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March 10, 1992

Full Surface Testing of Grazing Incidence Mirrors

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Sixth Quarter Report: Introductory Outline

The project goals for the first six quarters have been achieved. These include:

1. Prototype design,
2. Procurement and testing of components,
3. Mathematics and algorithm development,
4. Interferogram and data reduction algorithms,
5. Construction of first prototype,
6. Automated operation software development,
7. Construction and evaluation of modified prototype,
8. Integration of automated hardware controls and software, and
9. Testing of the full surface interferometer on aspheric optical surfaces.

The seventh and eighth (final) quarter goals are:

1. Writing of a users manual,
2. Additional testing and modification, and
3. Final report (eighth or final quarter).

This report is divided into two parts; the first part is systems design including detailed photographs of the optical head and the second part contains documentation of experimental results demonstrating the effectiveness of the Full Surface Scanning Interferometer.

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Subject: Quarterly Report: December 12, 1991 to March 11, 1992
(43 pages, including 31 figures)

FULL-SURFACE INTERFEROMETRIC TESTING OF GRAZING INCIDENCE MIRRORS

- Dr. Maurice Halioua: Optical Design and Testing
- Dr. Michael Liu: Digital Design and Testing

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FULL-SURFACE INTERFEROMETER TESTING OF GRAZING INCIDENCE MIRROR
SIXTH QUARTERLY REPORT: 12/12/91 to 03/12/92

SUMMARY

In the present report, we present the work done during the period of December 12, 1991 to March 11, 1992.

The tasks accomplished are as follows:

- The integration of the optical interferometer head, including the Oriel microstepper and the NEAT scanning stage

- The integration of the electronic hardware, including the CCD camera, the frame buffer, the Oriel microstepper controller and the NEAT scanning stage controller

- The integration of the software, including data acquisition and storage, Oriel microstepper control, NEAT scanning stage control, subaperture phase measurement and synthesis of full-surface phase measurement

- Initial testing of the complete integrated system, hardware and software, with presentation of experimental results of first full-surface measurement tests.

During the next periods, an extensive testing program will be carried out which will result in the following:

- Refinements of the optical, electronic and digital hardware systems

- Refinements in the software system and packaging of the software to increase speed and friendliness

- Assessment of performance such as speed and measurement accuracy.

1.0 **OPTICAL HARDWARE INTEGRATION**:

The optical interferometer head was integrated with the last three components as follows.

1.1 The Oriel Microstepper Stage

The Oriel microstepper, with a step resolution of one micron, was integrated into the grating subassembly in such a way that

- The grating can be finely translated in a direction perpendicular to the grating lines,
- The grating can be rotated by 90 degrees to change the direction of shear
- The grating can be axially translated to vary the focus.

The stepper is under computer control as described in the following section 2.0.

2.2 The NEAT Translation Stage

The NEAT translation stage was also integrated within the system. It holds the mirror under test and is used for scanning the mirror from subaperture to subaperture.

Under computer control, as described in the following section 2.0, it can be programmed for various scan lengths and subapertures widths. An example of scanning pattern is described in the last section 4.0.

2.3 The Mirror Alignment Assembly

The mechanical assembly that holds the mirror onto the NEAT stage has tilt and rotation adjustments to allow for aligning the mirror prior to scanning and phase measurement.

Note that, because we can visualize extended mirror area at a time, the alignment procedure is much eased when contrasted with the case of interferometer systems that yield single long traces only.

Figures 1 to 4 show photographs of the interferometer system:

- Figure 1 shows a photograph of the complete optical head
- Figure 2 shows the Oriel microstepper assembly (arrow)
- Figure 3 shows the rotating diffuser assembly used for noise reduction
- Figure 4 shows a close up photograph of the NEAT translation stage with cylindrical mirror under test.

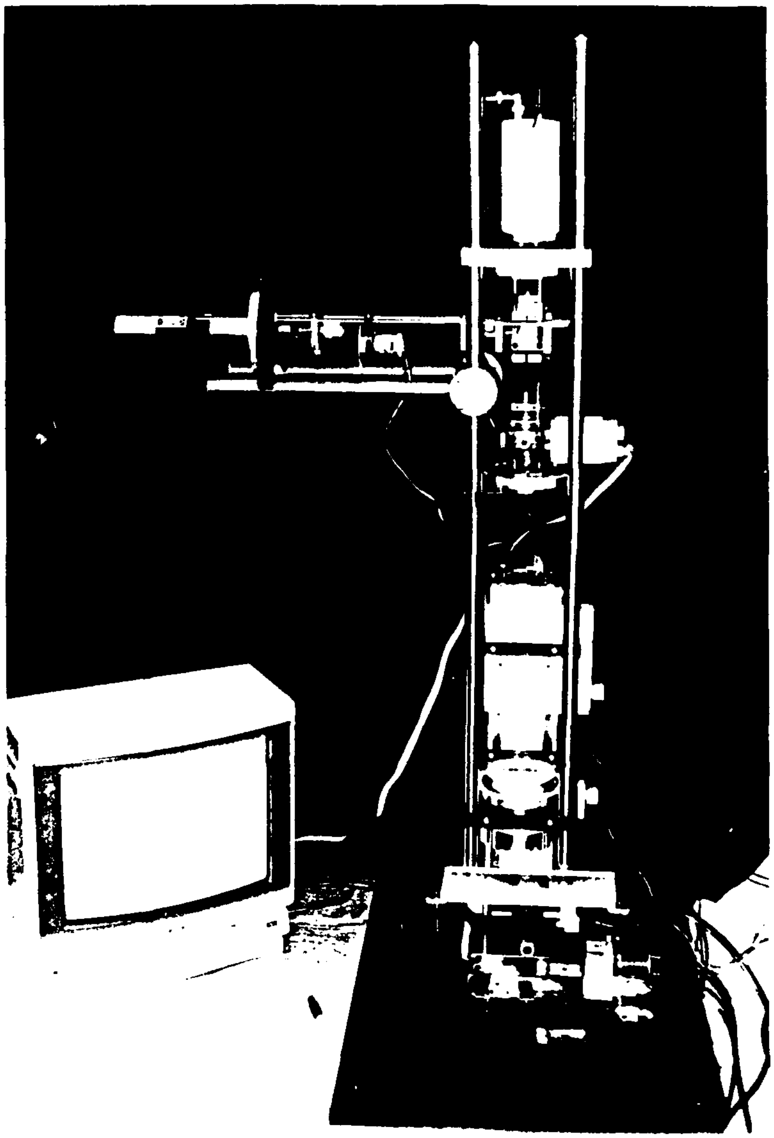


FIGURE 1: PHOTOGRAPH OF COMPLETE INTERFEROMETER HEAD

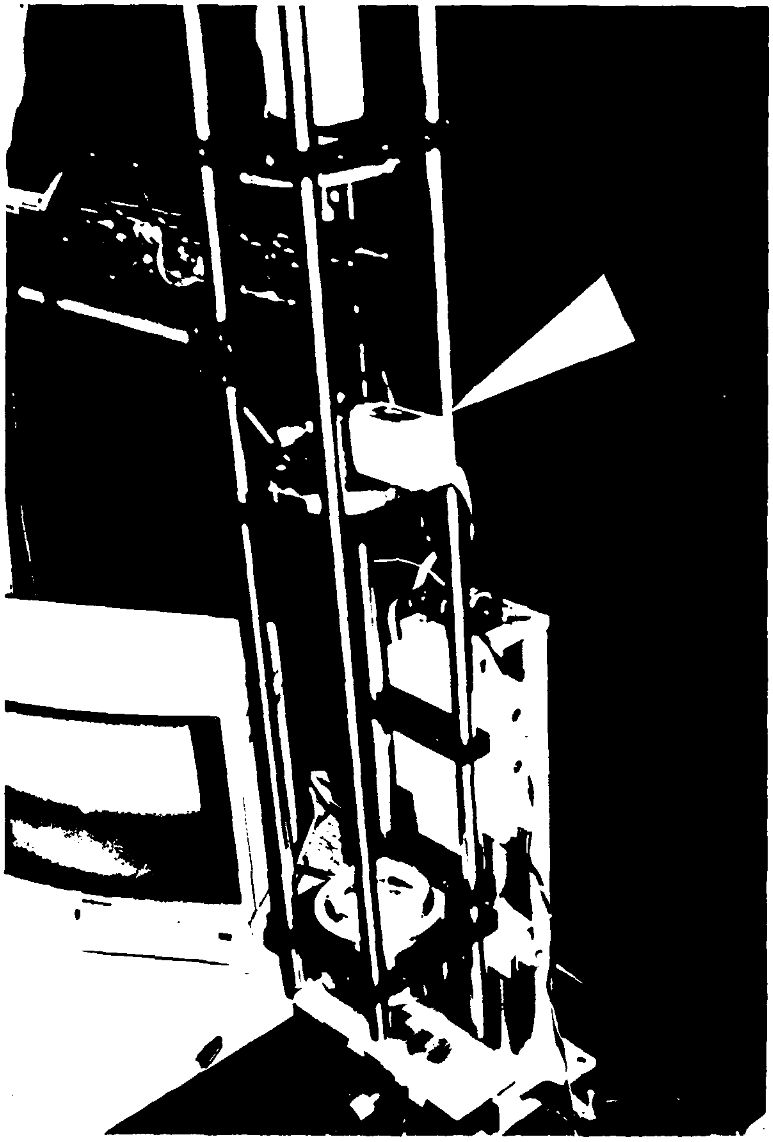


FIGURE 2: PHOTOGRAPH OF OPTICAL HEAD SHOWING THE ORIEL MICROSTEPPER ASSEMBLY

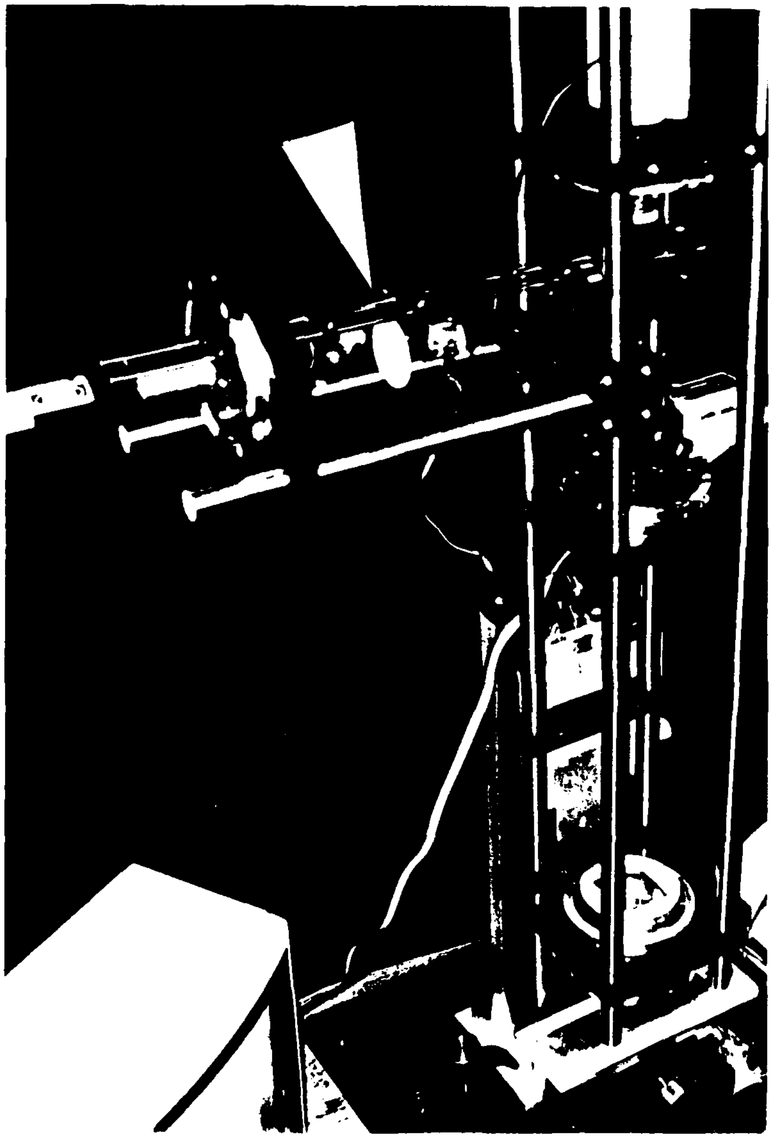


FIGURE 3: PHOTOGRAPH OF OPTICAL HEAD SHOWING THE ROTATING DIFFUSER SYSTEM (NOISE REDUCTION)

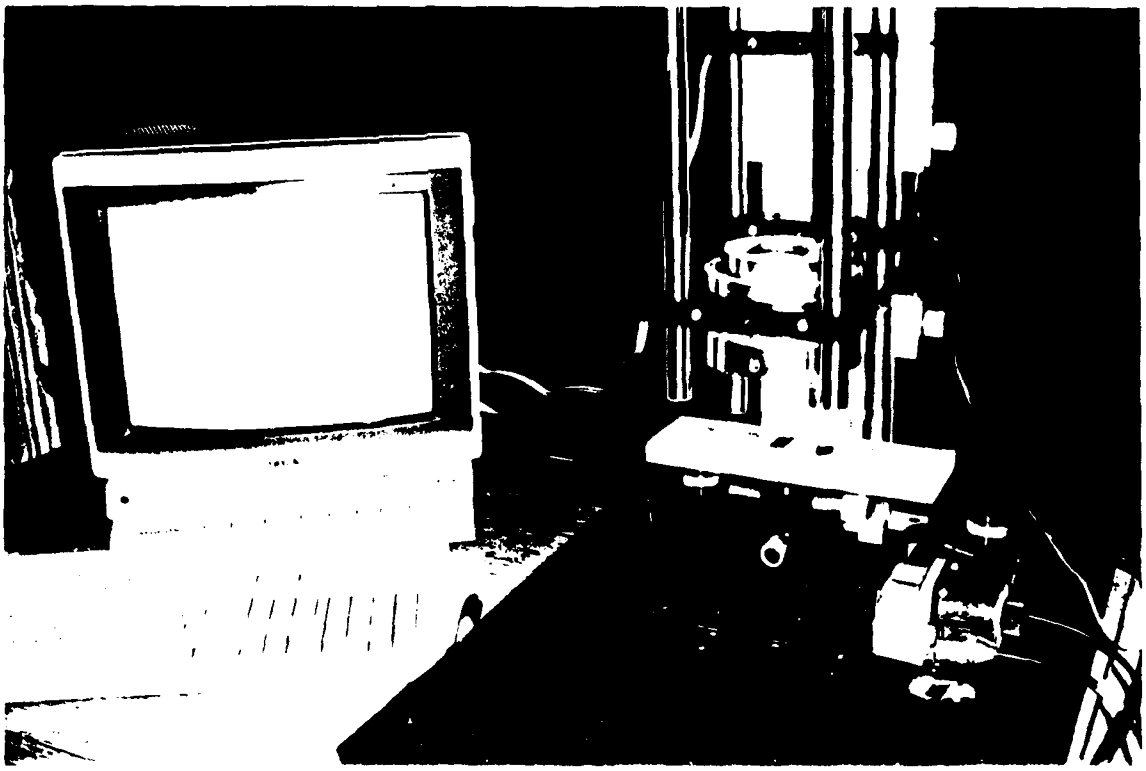


FIGURE 4: PHOTOGRAPH OF OPTICAL HEAD SHOWING A CLOSE-UP VIEW OF THE MIRROR SCANNING SYSTEM

2.0 **ELECTRONIC HARDWARE INTEGRATION**:

Three sub-systems are integrated under computer control:

- The Interferogram Acquisition System (CCD, Frame Buffer)
- The Grating Translation System (Oriel Microstepper)
- The Mirror Scanning System (NEAT Linear Stage)

The complete hardware integration system is shown in the Diagram 1 below.

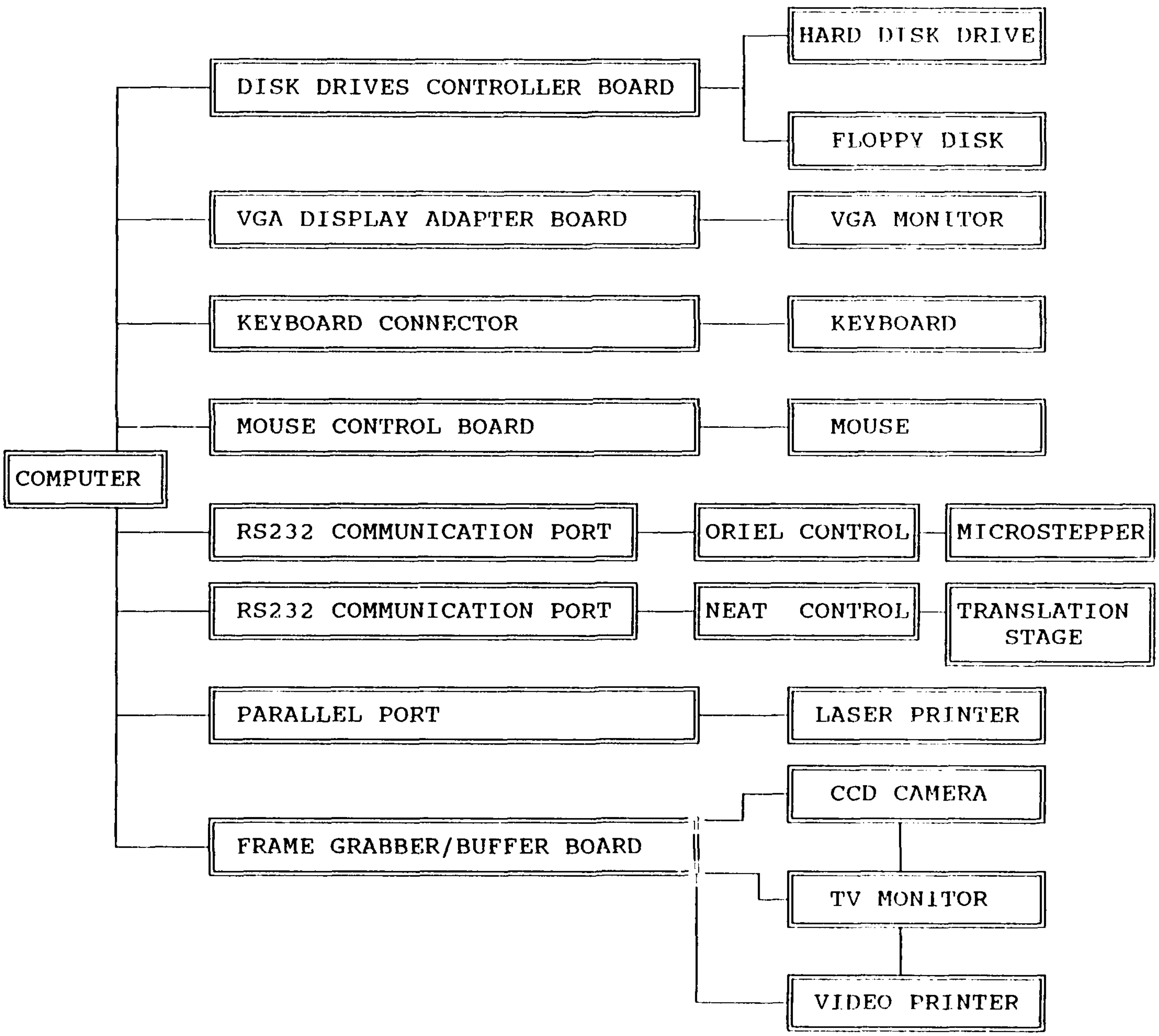


Diagram 1. Block Diagram of Electronic Hardware Integration

2.1 Acquisition System:

The acquisition system includes:

- An Imaging CCD Camera
- A Frame Grabber (A/D) and Frame Buffer
- A Monitor and a Video Printer

The integration is shown in the diagram 2 below.

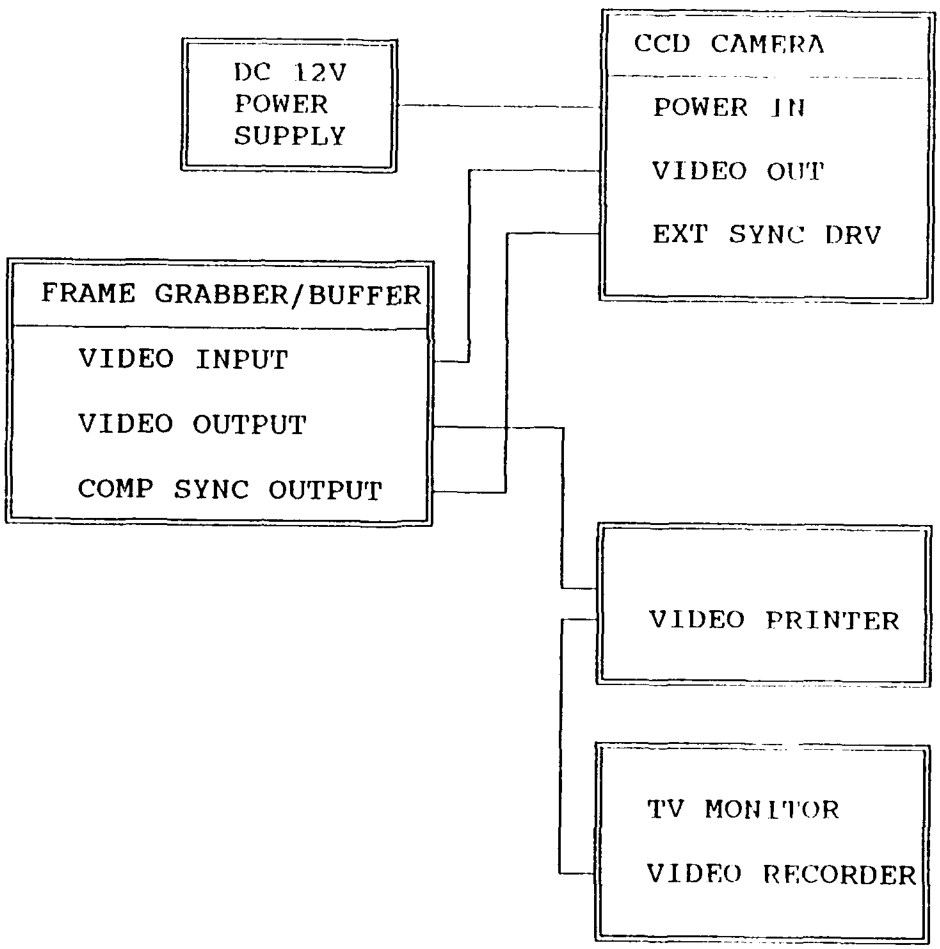


Diagram 2. Block diagram of the data acquisition and storage system

2.2 **Oriel Microstepper Control System**:

The Oriel Microstepper is used to shift the grating within the interferometer and is controlled through the computer serial port: RS232 COM1, as shown in Diagram 3. The detailed specifications of the controller and the wiring connections with the computer are described in section 2.2.1 below.

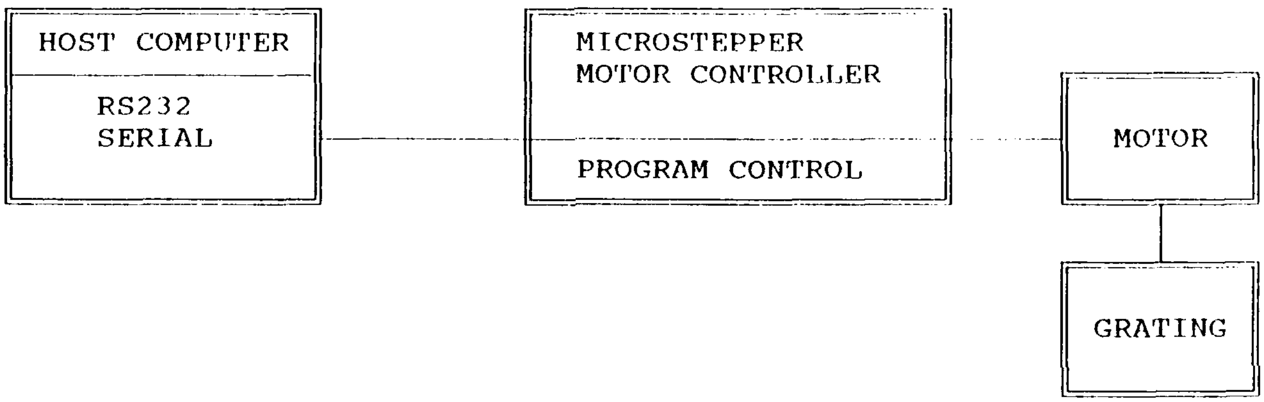


Diagram 3. Block Diagram of ORIEL Microstepper Control System

2.2.1. ORIEL MICROSTEPPER CONTROL SYSTEM SPECIATIONS

I. Controller Specifications

ORIEL RS 232 Stepper Interface Controller.

Specification:

Number of controlled stepper motors:	*Up to two, individually.*
Data I/O :	*300,600,1200,2400,4800,9600 baud, switch selectable.*
Compatible stepper motor:	*2 or 4 phase unipolar motor, 24V, 0.5 A max, per phase.*
Winding holding current:	*Reduced to 0.1 A per phase.*
Limit switch connections:	*Low logic level = limit reached.*
Maximum speed:	*Half step mode: 1000 steps / sec.*
Full step mode:	*500 steps / sec.*
Computer interface:	*RS 232.*
Power requirements:	*110/220-240 VAC 50/60 Hz, switch selectable.*

II. Control Motor Speciations

ORIEL Stepper Mike. Model 18500.

Specification:

Step Size:	*Half step mode: 1.3, 0.7 um.*
Full step mode:	*2 um.*
Maximum step rate:	*Half step mode: 1000 steps / sec.*
Full step mode:	*500 steps / sec.*
Maximum spindle speed:	*1 mm /sec.*
Maximum axial load:	*15.5 lbs.*
Uni-directional repeatability:	*< 2 um.*
Backlash:	*< 3 um.*
Travel Range:	*0.5", (13 mm).*

III. Controller/Computer Wiring Specification

Computer: RS232 9 pin (F) adapter.

2: (Red)
3: (Green)
5: (Black)
6,7,8: Short circuit.

Controller: 25 pin (M) adapter.

2: (Red)
3: (Green)
1,7: (Black)

Controller to Motor : 10 lines Rainbow cable.

IV. Control Software Command Set Specification

RS 232 serial control, 7 data bit, 1 stop bit, no parity bit, ASCII data format.

Command Set:

A,B: Direct the flow of command, data, status inquiries to motor control register.
C: Clear absolute register to zero, (set logic origin).
D: Disable motor driver.
E: Enable the motor driver.
F: Change to full step mode.
G: Go absolute.
Format G +/- dddd, ',' is necessary to stop data field.
dddd is the number of steps to go.
H: Change to half step mode.
I: Inquire the status of motor. return 'd', d = 0 - 7
bit 0, direction: CW = 1 , CCW = 0.
bit 1, step size: half = 1 , full = 0.
bit 2, E/D status: Enable = 1, disable = 0.
Q: Inquire the status of translator. return 'd', d = 0 - 7
bit 0, motor: On = 1 , Off = 0.
bit 1, CW limit: yes = 1 , no = 0.
bit 2, CCW limit: yes = 1 , no = 0.
R: Set up the desired step rate for each motor.
Format: Rn, n = 0 - 7.
S: To start the moving.
T: Travel relative steps.
Format: Tdddddddd,
Z: Move to the logic origin.(the position of absolute register = 0)
@: Unconditional stop both motor.
>: Move single step in CW direction.
<: Move single step in CCW direction.
=: Start both motors simultaneously.
** After command set, eg AT1000,BT1000.*
+: Set direction to CW.
-: Set direction to CCW.

2.3 **NEAT TRANSLATION STAGE CONTROL SYSTEM**

The NEAT translation stage is used for scanning the mirror under test and its operation is shown in Diagram 4. The detailed specifications of the controller and the wiring connections with the computer are described in section 2.3.1 below.

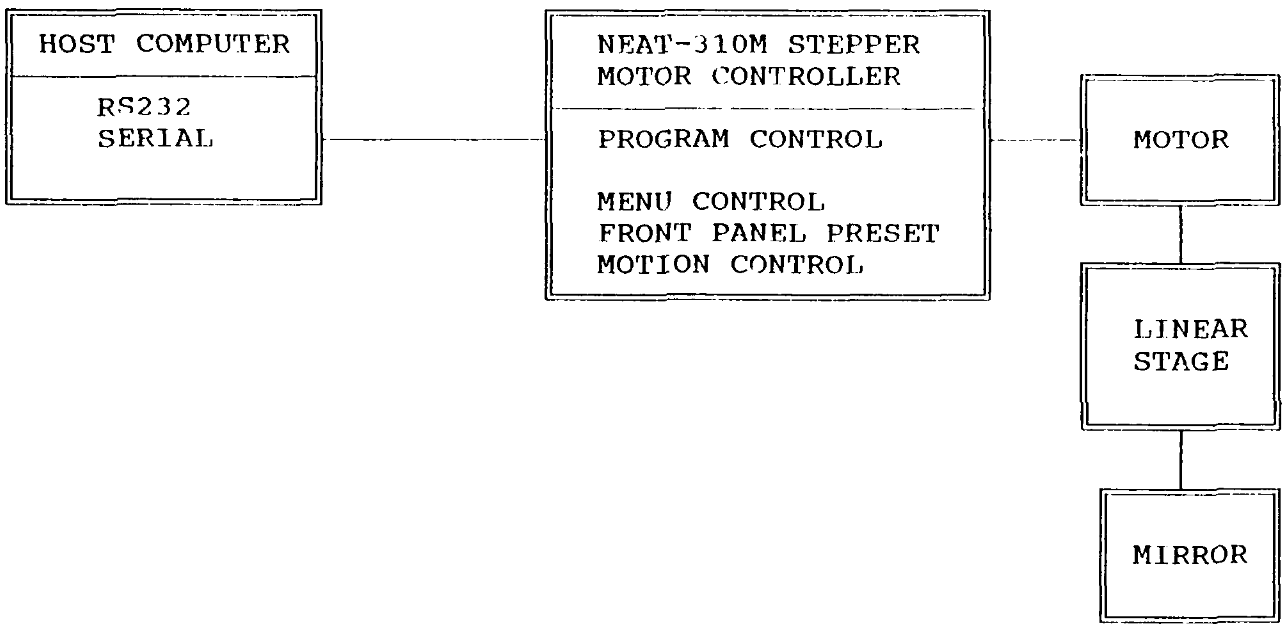


Diagram 4. Block Diagram of NEAT Translation Stage Control System

2.3.1 NEAT TRANSLATION STAGE CONTROL SYSTEM

I. Controller Specification.

NEAT-310M Programmable Stepping Motor Controller.

Specification:

Drive Type:	*54 volt bipolar chopper*
	.7 to 3.5 Amps/Phase, half-coil
	1.5 to 7 Amps/Phase, full-coil.
Memory buffer:	*8 or 32 K bytes non-volatile program memory*
Velocity Range:	*40 to 327,640 steps / sec.*
	40 Hz resolution.
Position Range:	*-8,388,608 to +8,388,608 steps*
Computer interface:	*RS 232. / 8 bit parallel communication port*
Power requirements:	*115/230 V A.C. 50/60 Hz, 1.5 Amps*

II. Control Software Command Set Specification.

RS 232 serial control, 8 data bit, 1 stop bit, no parity bit, ASCII data format.

Command Set:

MR: Move relative.
Format: MRddddddd ddddddd range from -8,388,608 to + 8,388,608
MA: Move absolute.
Format: MAddddddd ddddddd range from -8,388,608 to + 8,388,608
MH: Move physical origin position.
MC: Move continuous.
Format MC+/-.
SP: Set absolute register counter value.
VI: Set initial velocity.
Format: VIddddddd ddddddd range from 40 to 327,680
default is 4000 steps / sec.
The primary resonance is at 400-1200 steps / sec. the maximum allowable start/stop frequency is load dependent, typically below 6000 / sec is safe.
VF: Set final velocity.
Format: VFddddddd ddddddd range from 40 to 327,680
AC: Set acceleration and deceleration.
Format: AC(+/-)ddddddd , '+' for acceleration, '-' for deceleration, without sign for both.
ST: Stop moving immediately.
ME: Mnemonic Expansion.
Format: MFE for enable, MED for disable.
MF: Move finish signal feed back.
Format: MFE for enable, MFD for disable.

III. Controller/Computer Wiring Specification.

Computer: RS232 9 pin (F) adapter.

2: (Red)
3: (Green)
5: (Black)
6,7,8: Short circuit.

Controller: 25 pin (M) adapter.

2: (Green)
3: (Red
1,7: (Black)

3.0 **SOFTWARE INTEGRATION**:

An initial software integration package has been completed and tested. The software includes the following operations:

- Data Acquisition and Storage of Subaperture Interferograms
- Grating Control
- Translation Stage Control for Mirror Scanning
- Phase measurement of Subaperture Interferograms
- Full Surface Synthesis from Subaperture Interferograms.

Experimental results are given in the following section.

4.0 EXPERIMENTAL RESULTS

Initial testing was carried out with the integrated interferometer system. Extensive testing will be carried out during the next periods in order to further refine the optical, mechanical and electronic hardware, as well as to refine the software package.

The test surface was a long, convex cylindrical mirror. The mirror was custom made for this project and includes for generality: low frequency shape errors a well as high frequency local errors.

A 6-inch scan length was used, which was further divided into 5 overlapping 2-inch subapertures. The slope phase function in the direction of the length of the mirror was computed for each of the 5 subapertures. Then a complete single function was synthesized by least square fitting the overlap areas to remove piston and tilt mismatches.

- Figures 5a to 5e show photographs of the 5 subaperture interferograms

- Figure 6 shows the 3 adjacent subaperture interferograms together

- Figure 7 shows the 5 subaperture interferograms together.

- Figures 8a to 8e' show the result of the phase measurement and, for each subaperture, displays a contour map (2pi/10 steps) and a three-dimensional isometric plot

- Figures 9a to 9d show the result of the phase measurement in the vicinity of the overlap area. Note that the horizontal line indicates the separation between the 2 corresponding subapertures. Fringe continuity between adjacent areas is a measure of the quality of the fitting procedure

- Figures 10a to 10b' show the full-surface synthesis from the 5 raw subaperture interferograms: three-dimensional isometric plot and contour maps (2pi/5 and 2pi/10 steps)

- Figures 11a to 11b' show the full-surface synthesis after digital removal of a global tilt function to display the pure surface errors: three-dimensional isometric plot and contour maps (2pi/10 and 2pi/20 steps).

Note that the horizontal lines were added on to indicate the lines of separations of the different subapertures.

These initial results clearly show that the fitting was quite successful as indicated by the continuity of the contour levels from subaperture to subaperture in the vicinity of the horizontal lines of separation.

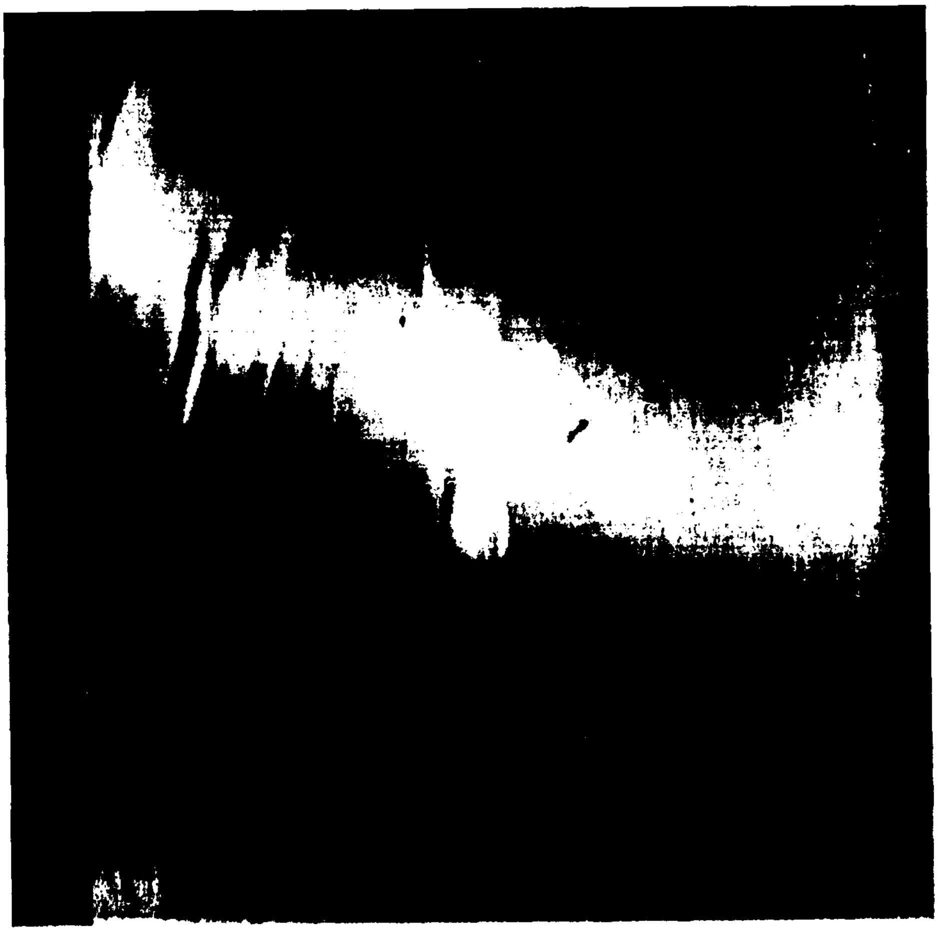


FIGURE 5A: PHOTOGRAPH OF SUBAPERTURE INTERFEROGRAM #1

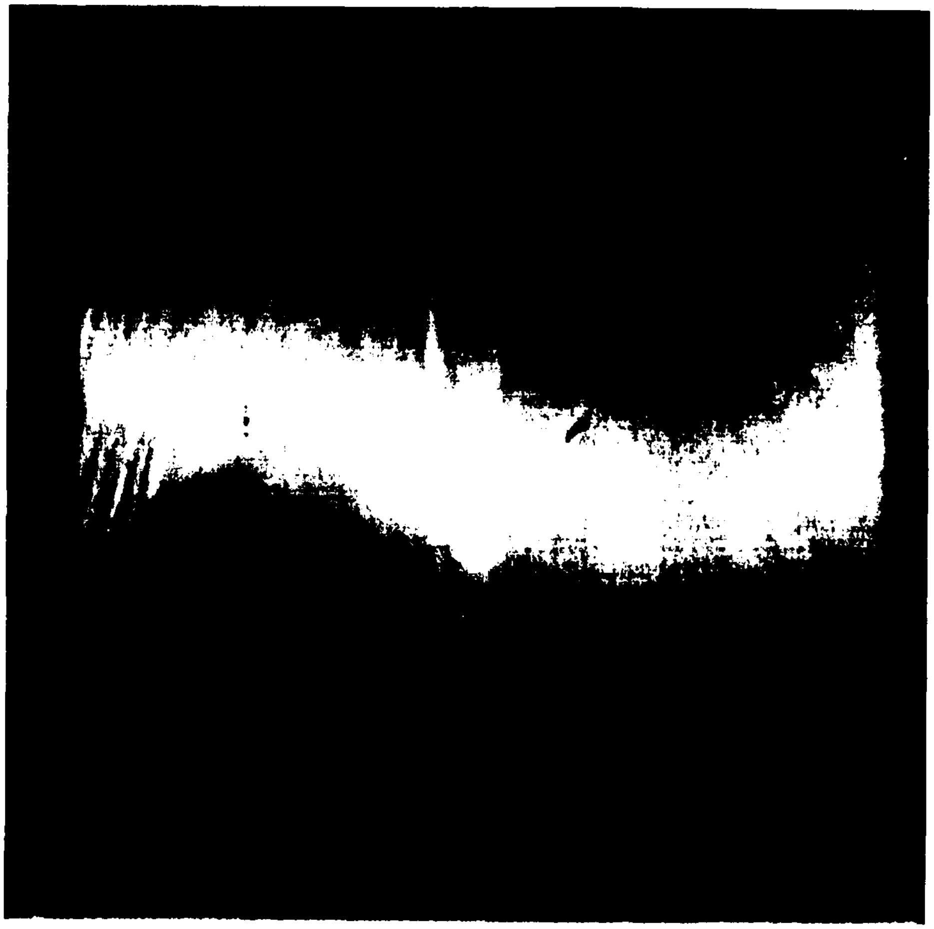


FIGURE 5B: PHOTOGRAPH OF SUBAPERTURE INTERFEROGRAM #2

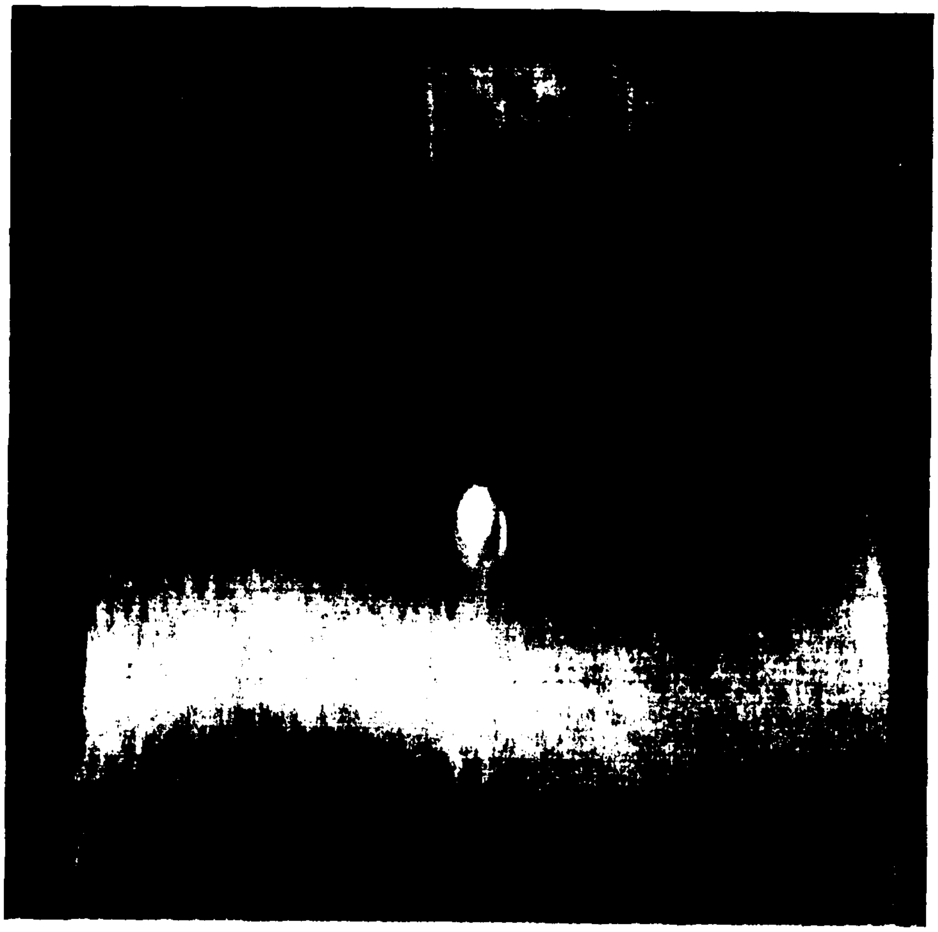


FIGURE 5C: PHOTOGRAPH OF SUBAPERTURE INTERFEROGRAM #3

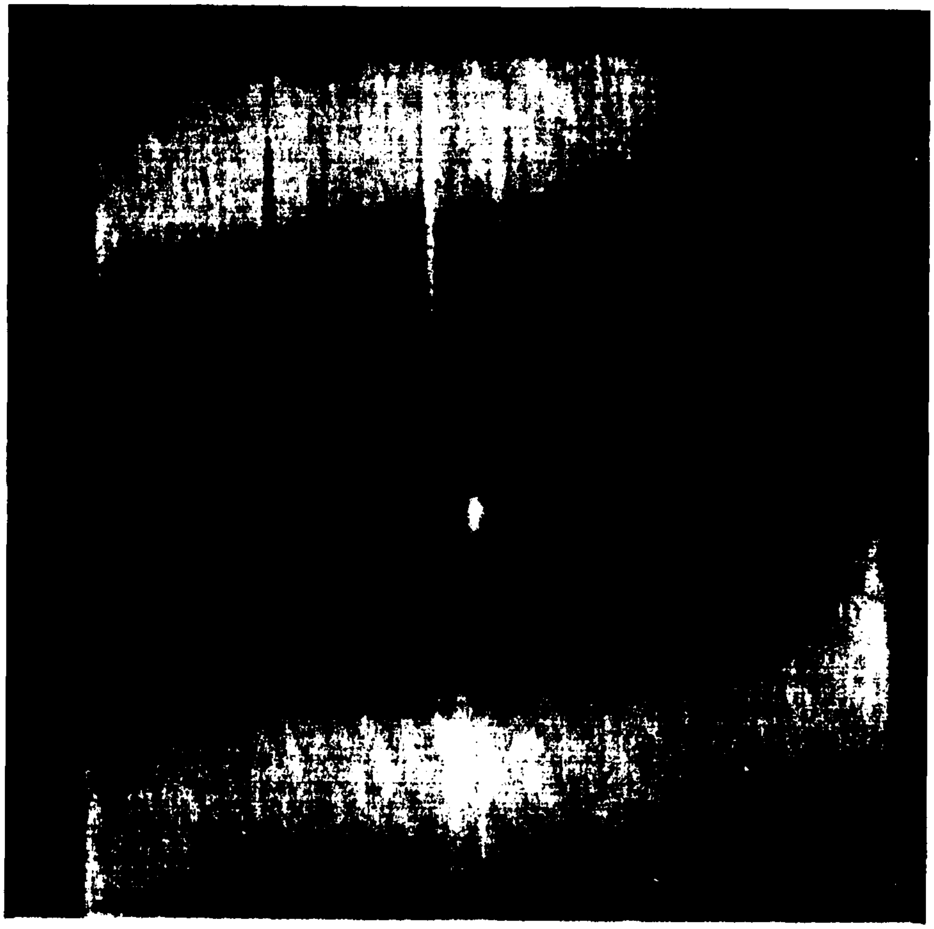
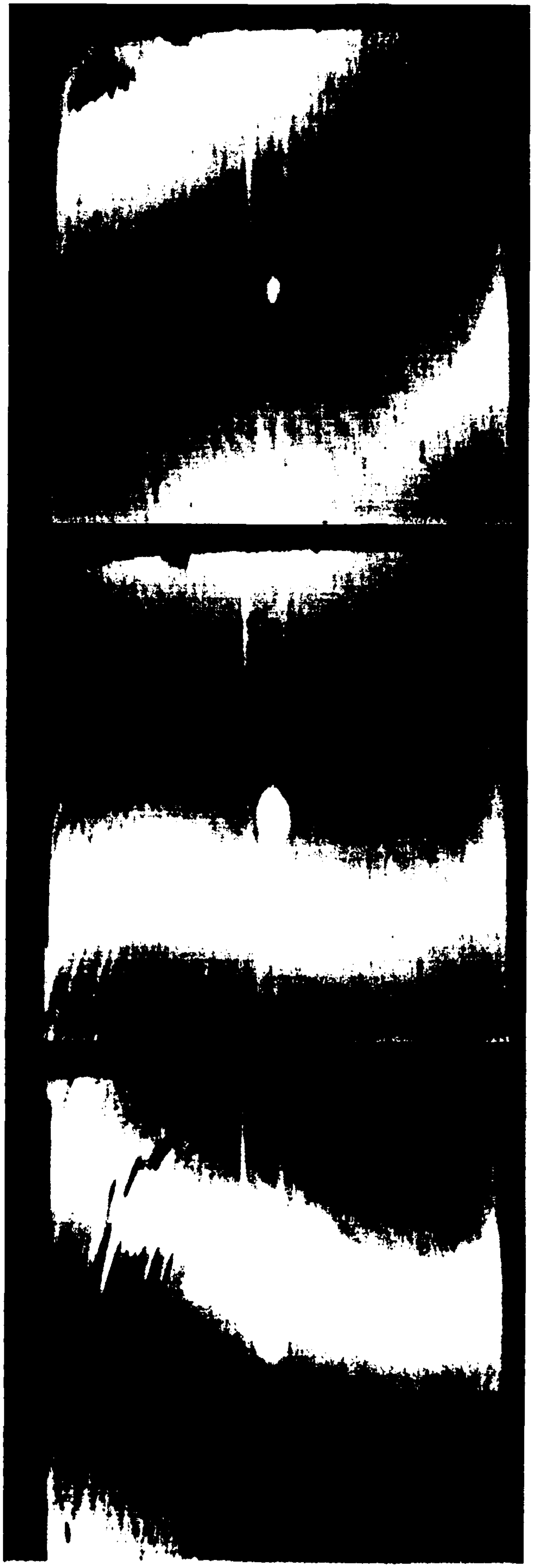


FIGURE 5D: PHOTOGRAPH OF SUBAPERTURE INTERFEROGRAM #4

FIGURE 5E: PHOTOGRAPH OF SUBAPERTURE INTERFEROGRAM #5

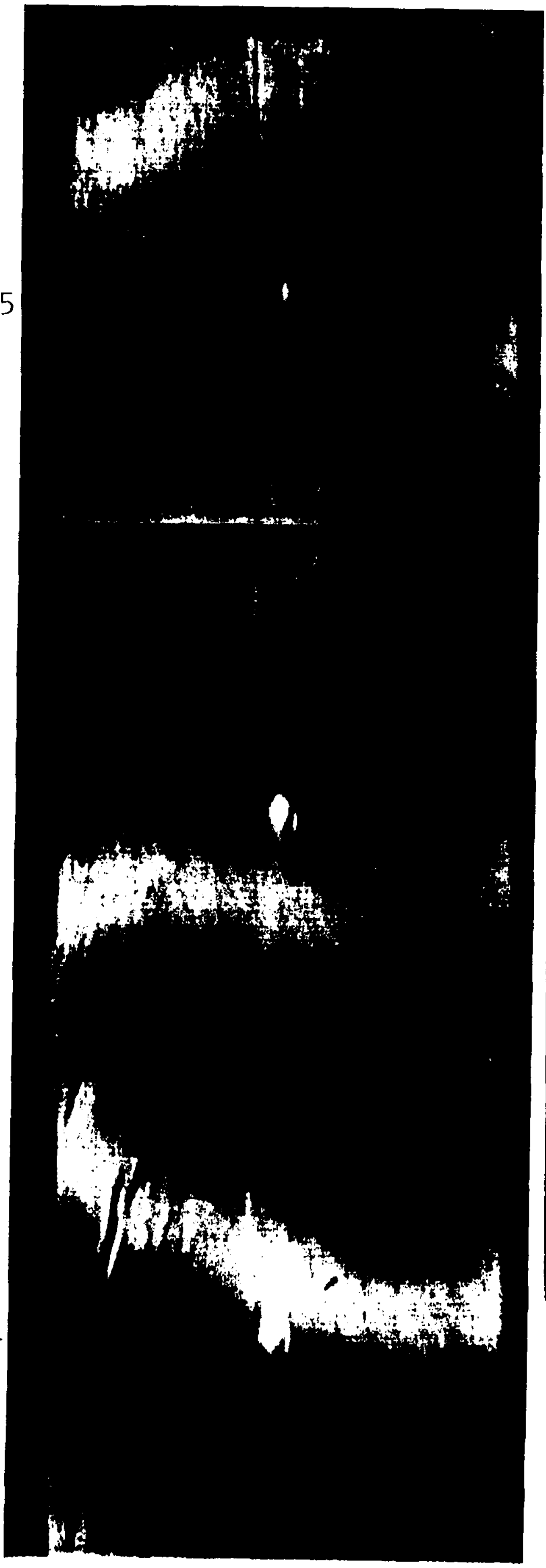


SUBAPERTURE
5

SUBAPERTURE
3

SUBAPERTURE
1

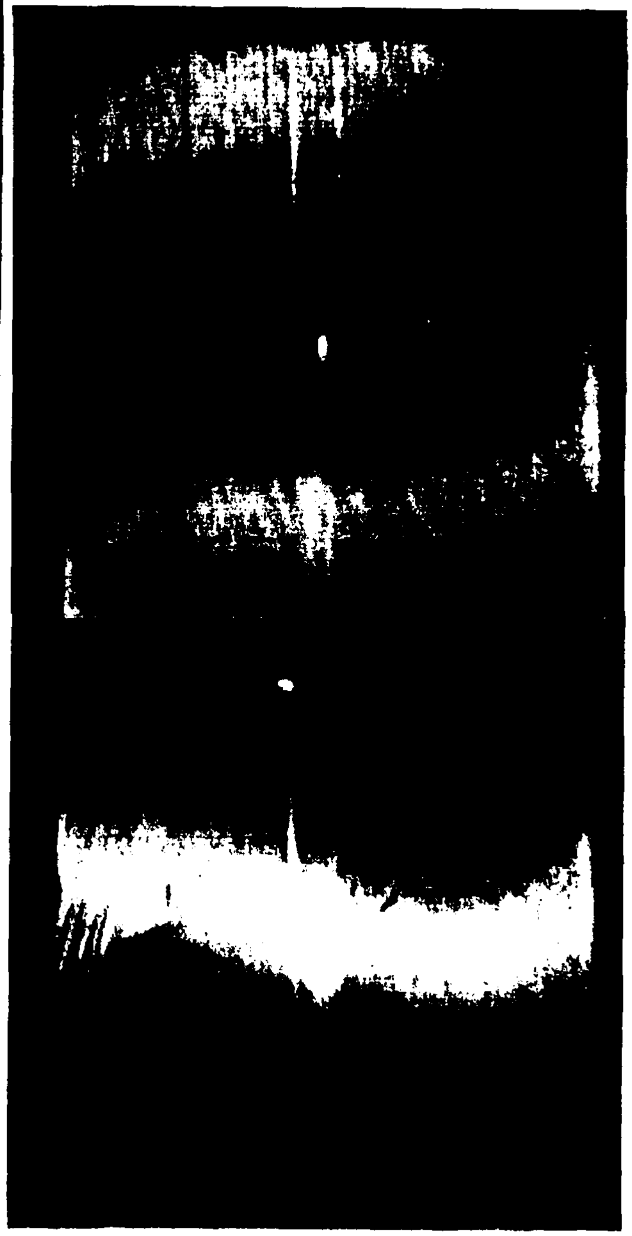
FIGURE 6: PHOTOGRAPHS OF ADJACENT SUBAPERTURE INTERFEROGRAMS



UB.5

JB.3

UB.1



SUB.4

SUB.2

FIGURE 7: PHOTOGRAPHS OF SERIES OF 5 SUBAPERTURE INTERFEROGRAMS

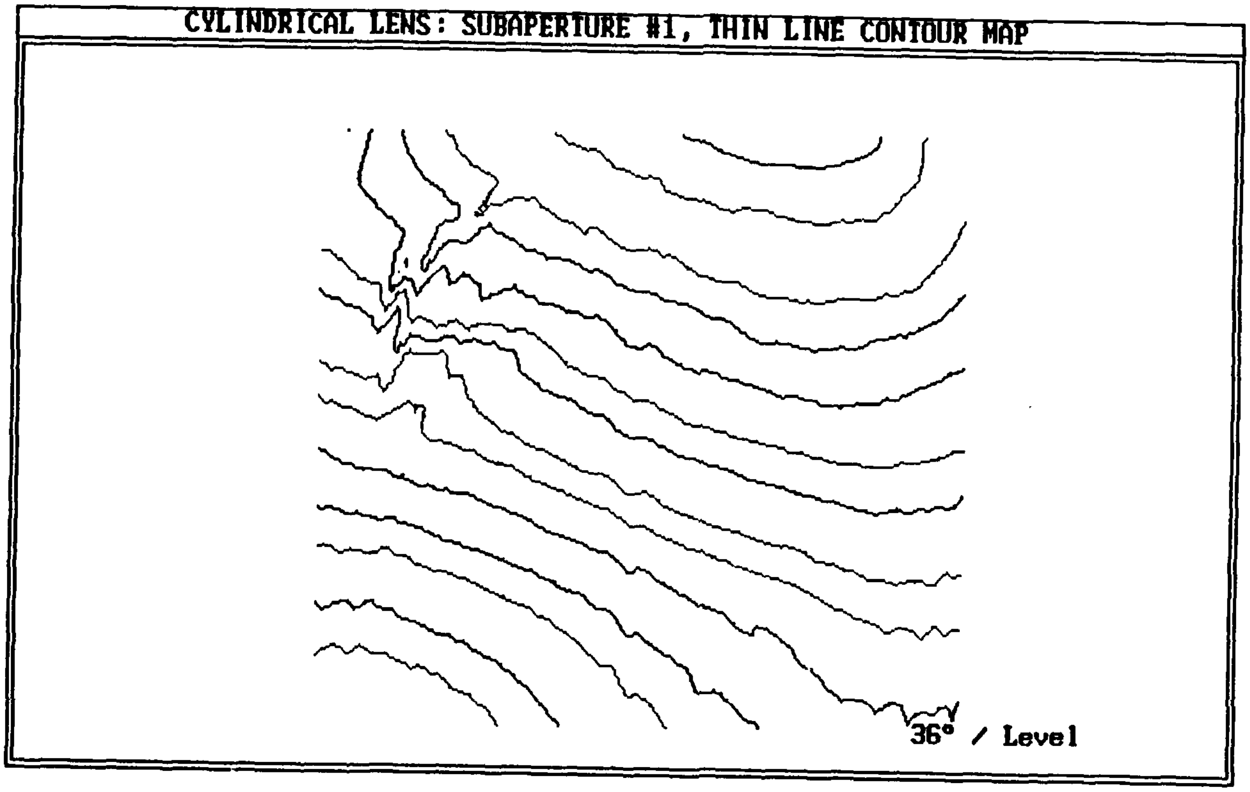


FIGURE 8A: PHASE MEASUREMENT OF SUBAPERTURE INTERFEROGRAM # 1 (CONTOUR MAP)

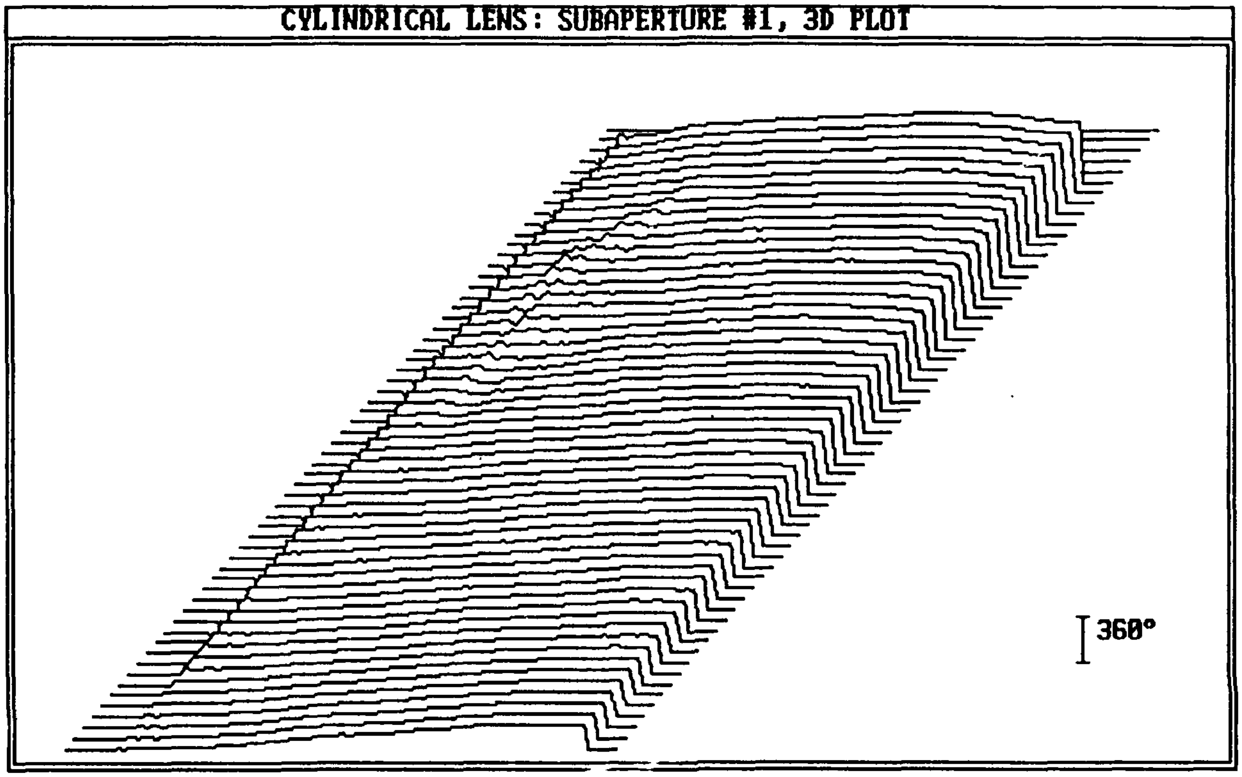


FIGURE 8A': PHASE MEASUREMENT OF SUBAPERTURE INTERFEROGRAM # 1
(3-D ISOMETRIC PLOT)

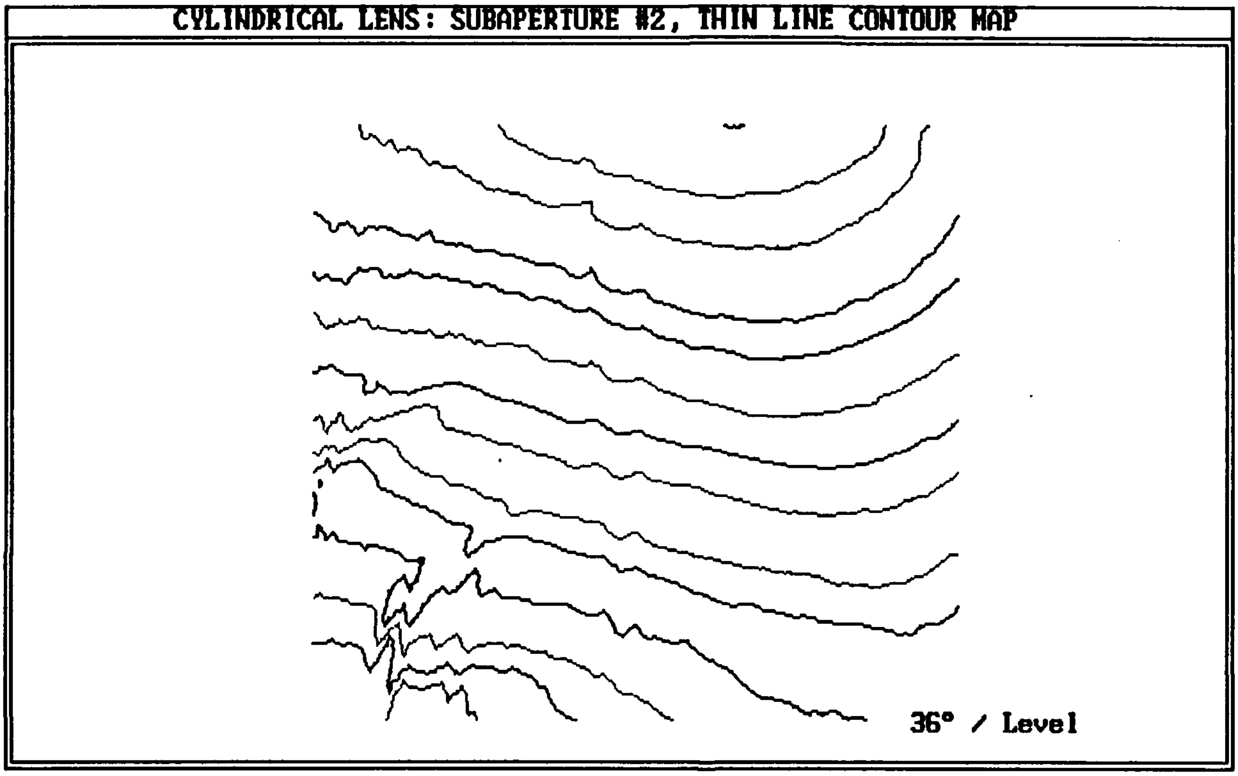


FIGURE 8B: PHASE MEASUREMENT OF SUBAPERTURE INTERFEROGRAM # 2
(CONTOUR MAP)

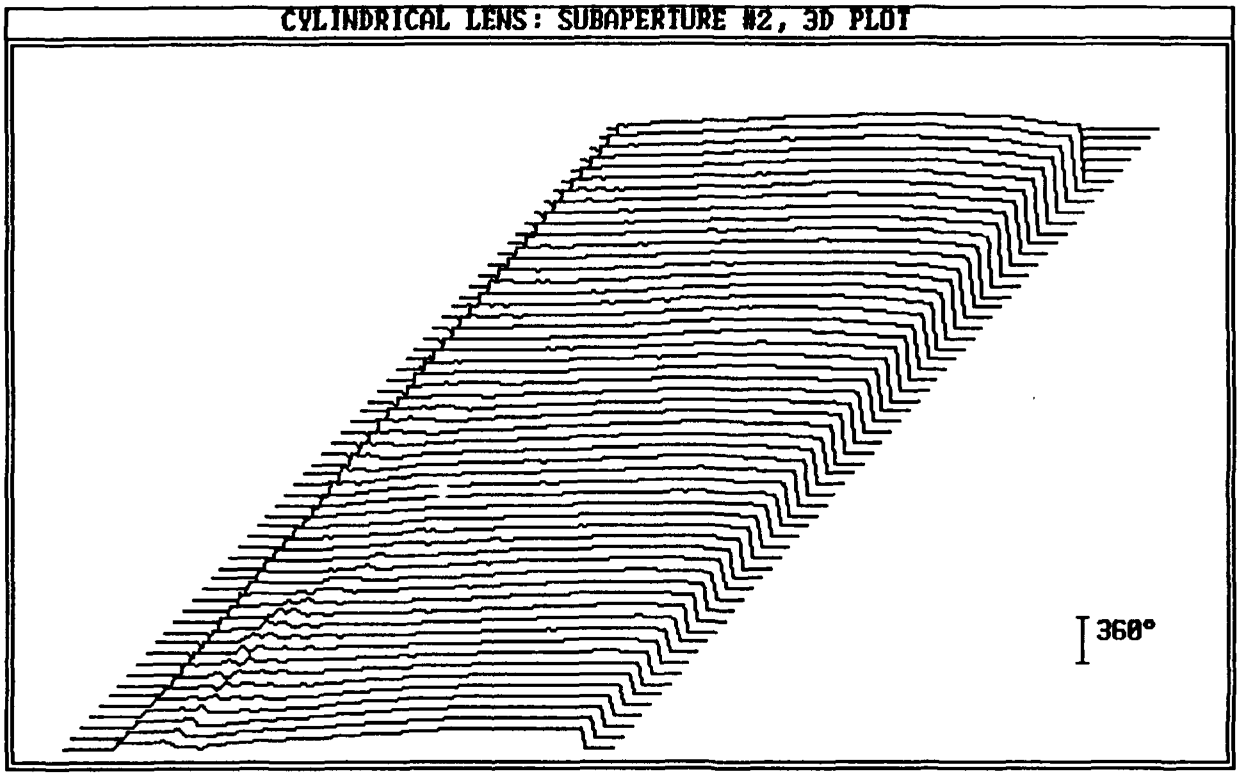


FIGURE 8B': PHASE MEASUREMENT OF SUBAPERTURE INTERFEROGRAM #2
(3-D ISOMETRIC PLOT)

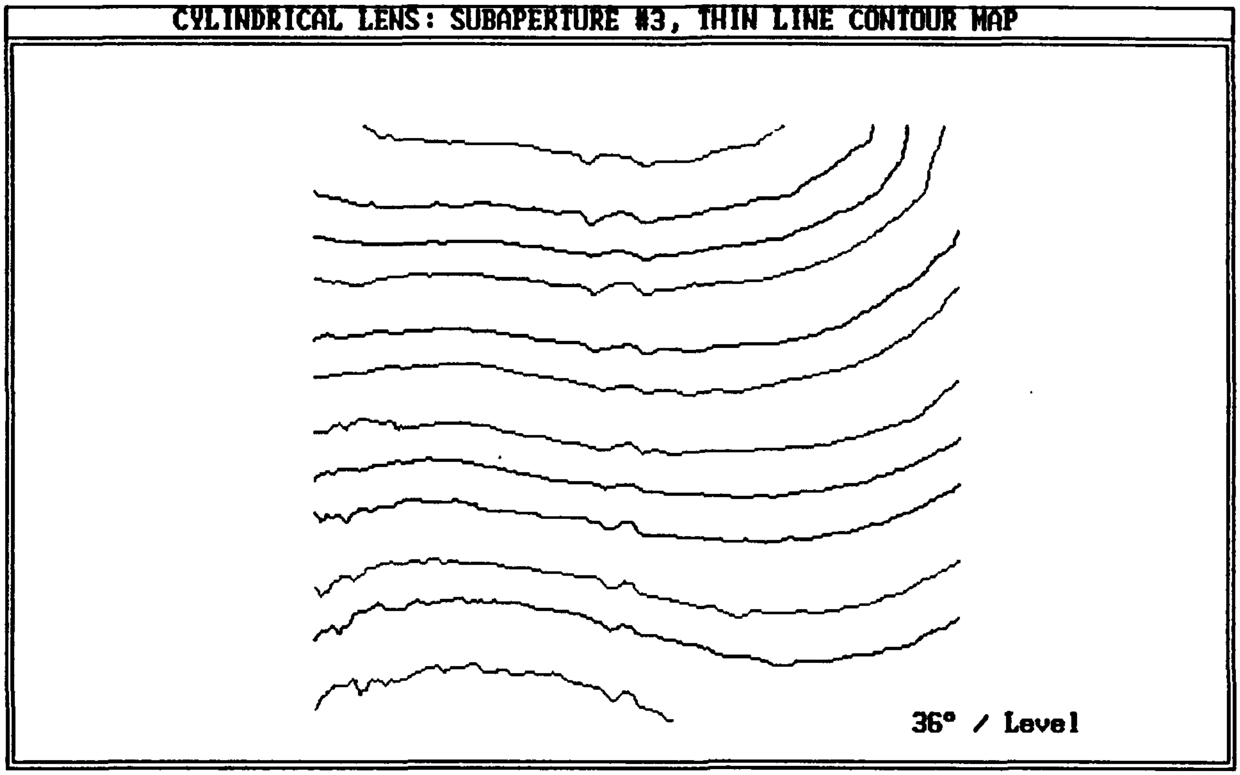


FIGURE 8C: PHASE MEASUREMENT OF SUBAPERTURE INTERFERPGRAM #3
(CONTOUR MAP)

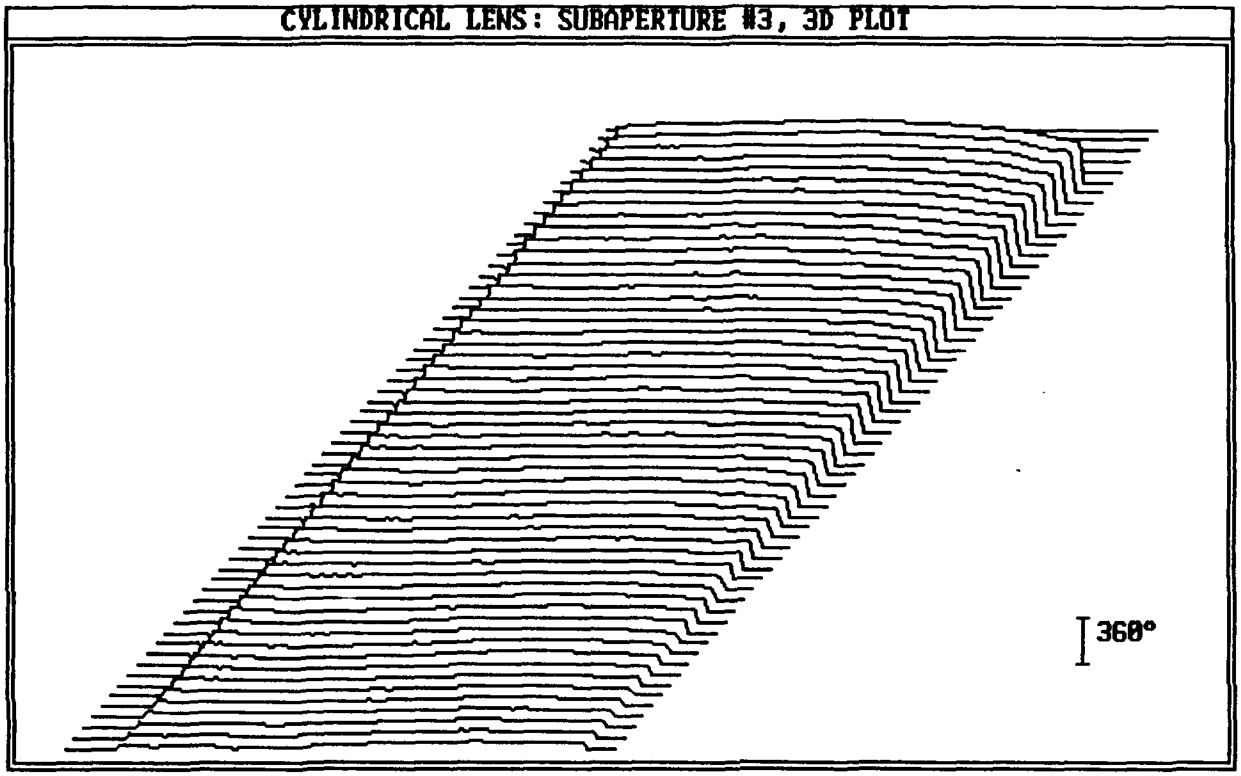


FIGURE 8C': PHASE MEASUREMENT OF SUBAPERTURE INTERFEROGRAM # 3
(3-D ISOMETRIC PLOT)

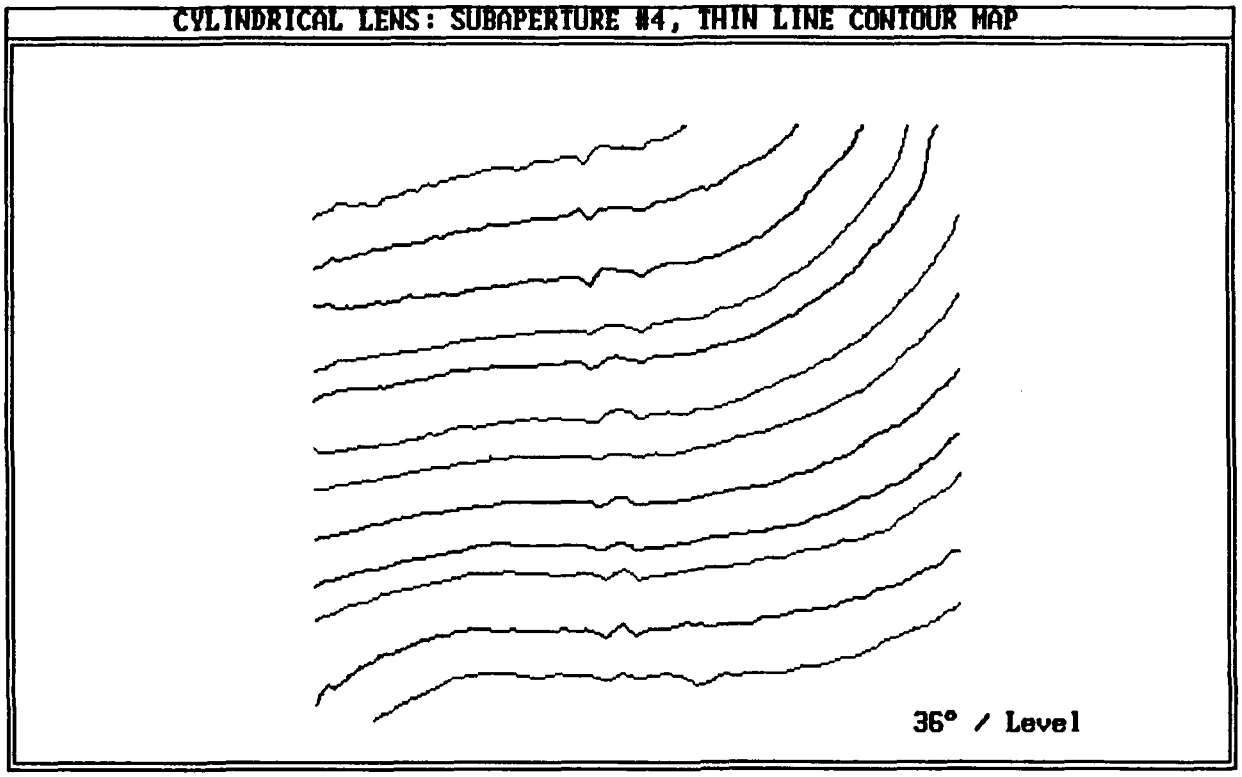


FIGURE 8D: PHASE MEASUREMENT OF SUBAPERTURE INTERFEROGRAM # 4
(CONTOUR MAP)

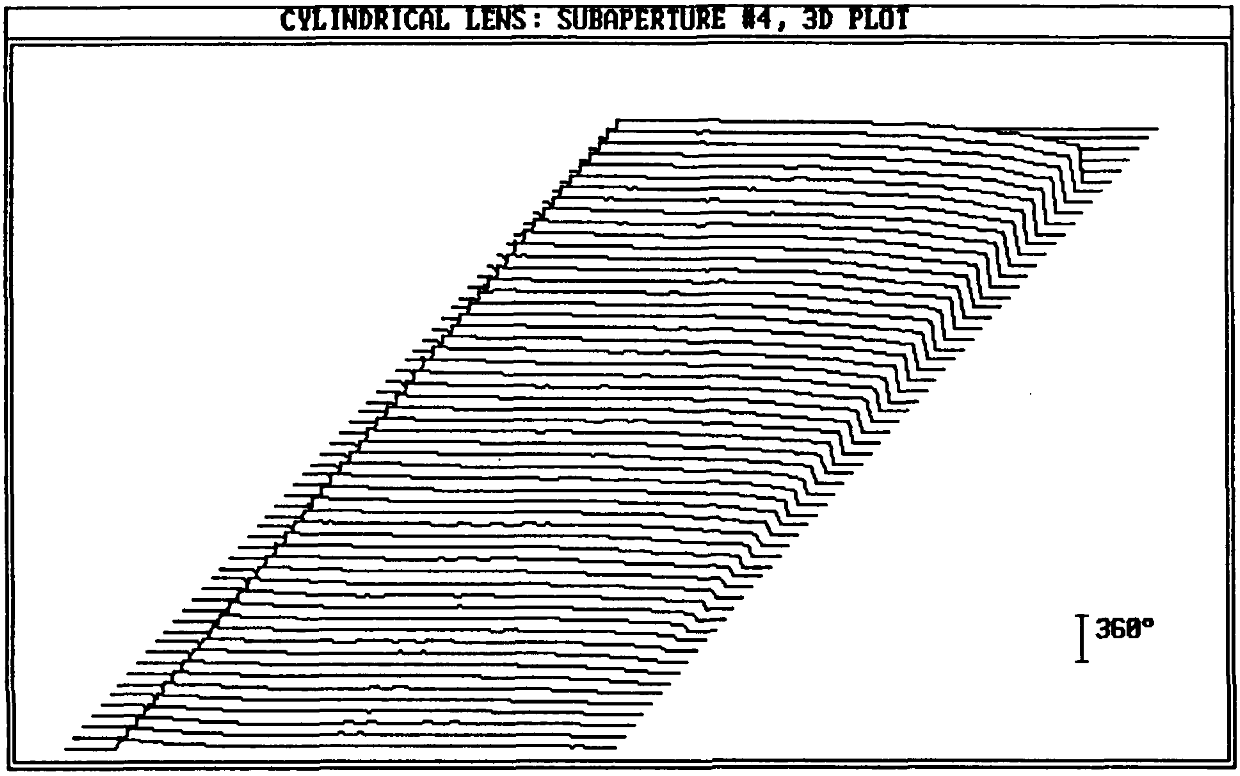


FIGURE 8D': PHASE MEASUREMENT OF SUBAPERTURE INTERFEROGRAM # 4
(3-D ISOMETRIC PLOT)

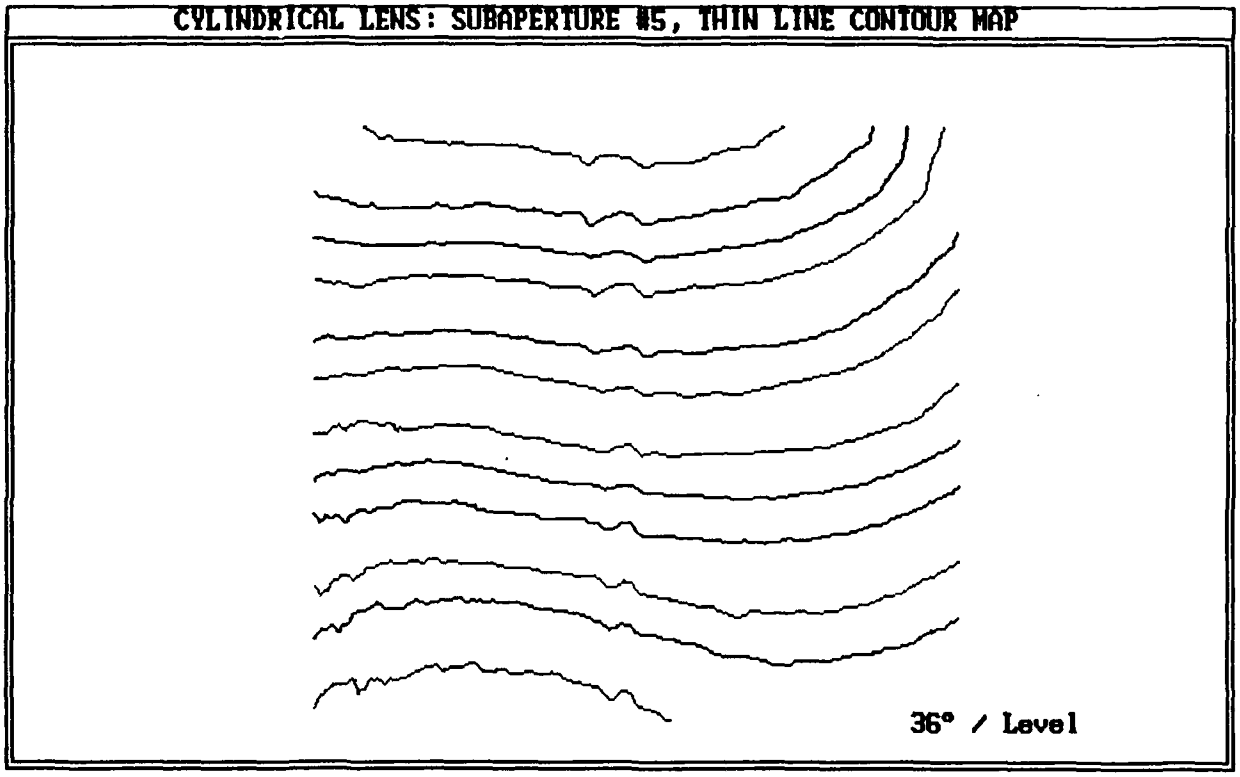


FIGURE 8E: PHASE MEASUREMENT OF SUBAPERTURE INTERFEROGRAM # 5 (CONTOUR MAP)

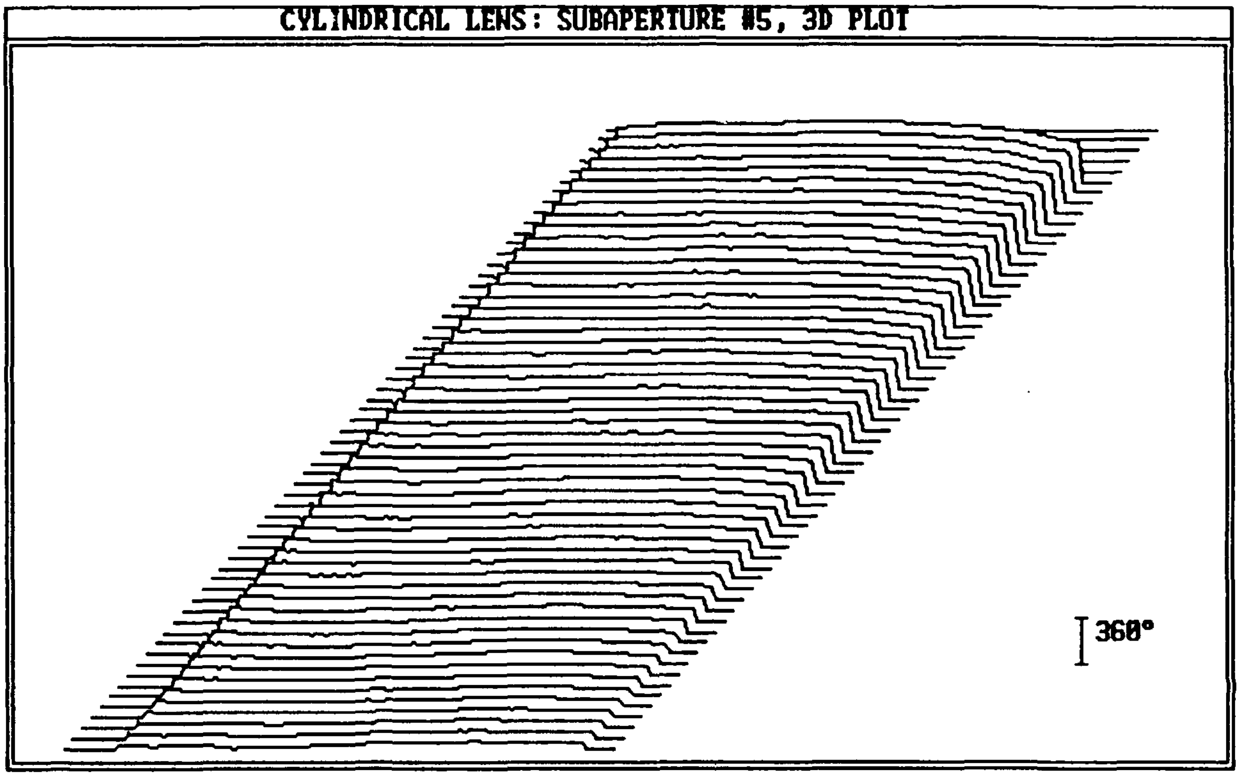


FIGURE 8E': PHASE MEASUREMENT OF SUBAPERTURE INTERFEROGRAM # 5
(3-D ISOMETRIC PLOT)

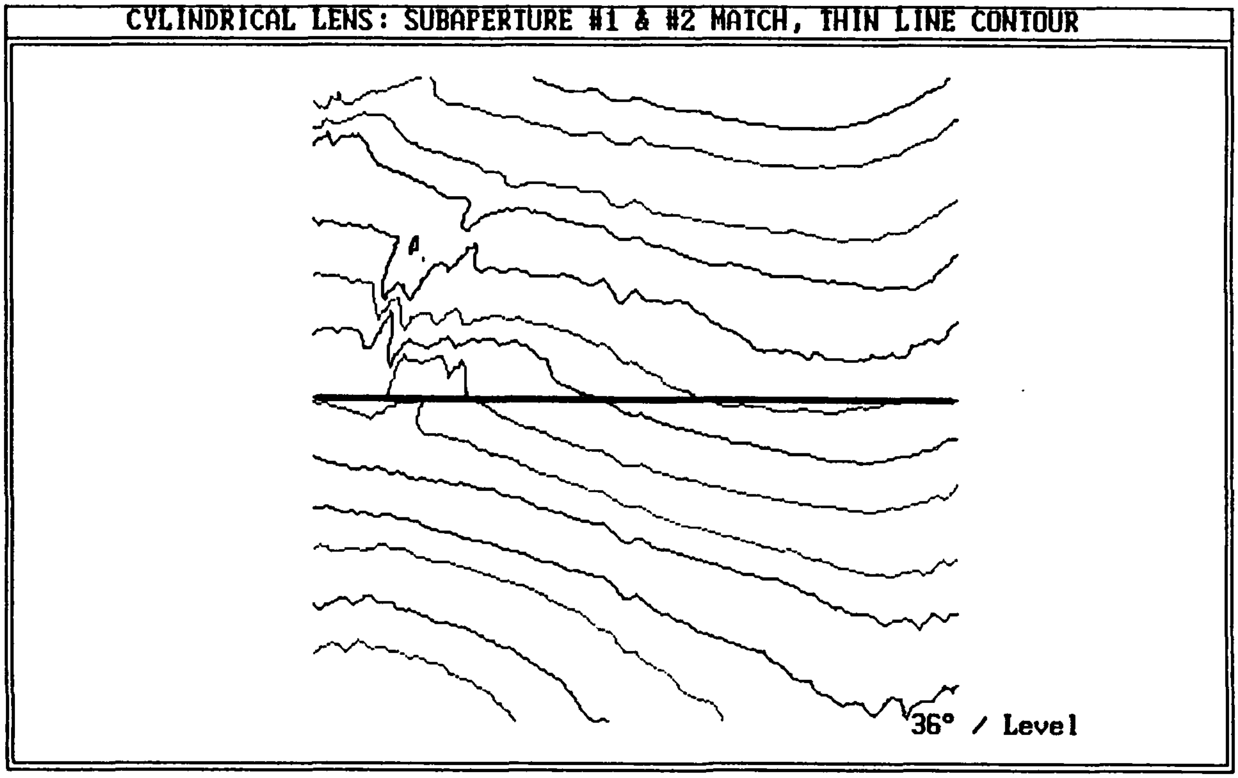


FIGURE 9A: PHASE MEASUREMENT SHOWING LEAST SQUARE FITTING IN OVERLAP REGION FOR SUBAPERTURE INTERFEROGRAMS # 1 AND 2

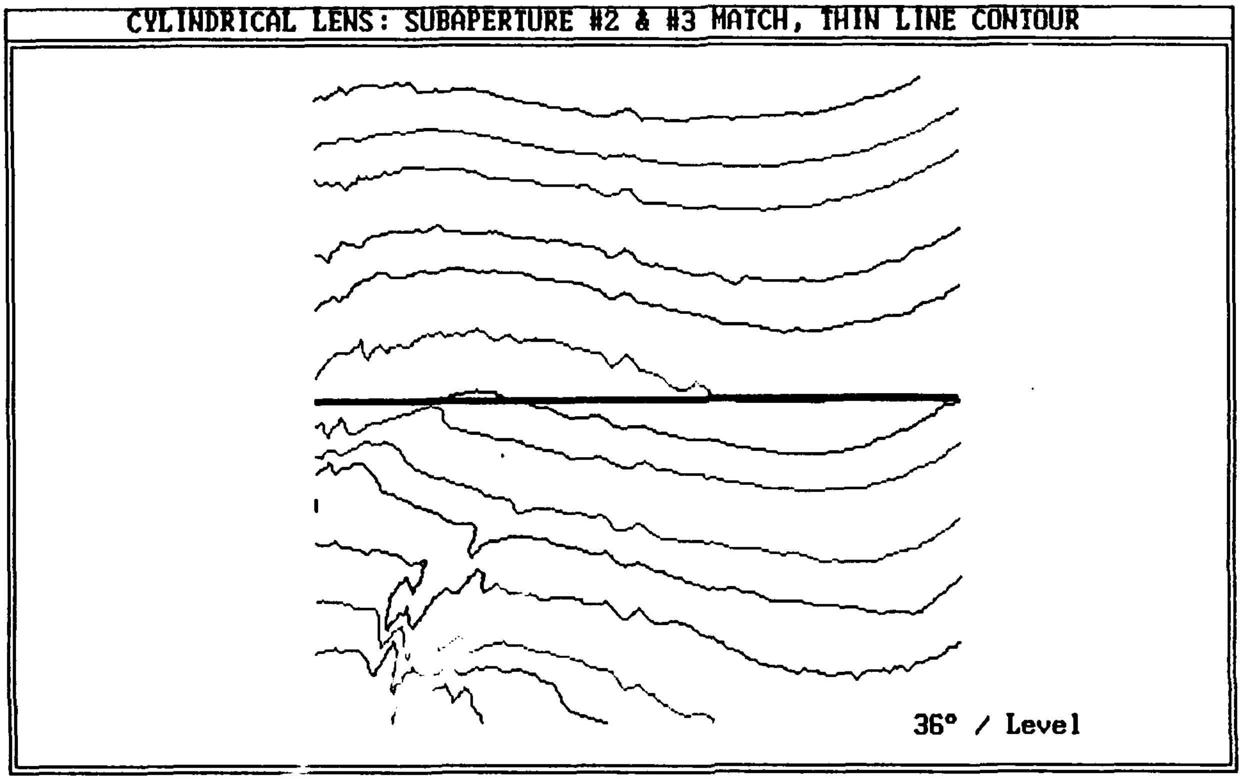


FIGURE 9B: PHASE MEASUREMENT SHOWING LEAST SQUARE FITTING IN OVERLAP REGION FOR SUBAPERTURE INTERFEROGRAMS # 2 AND 3

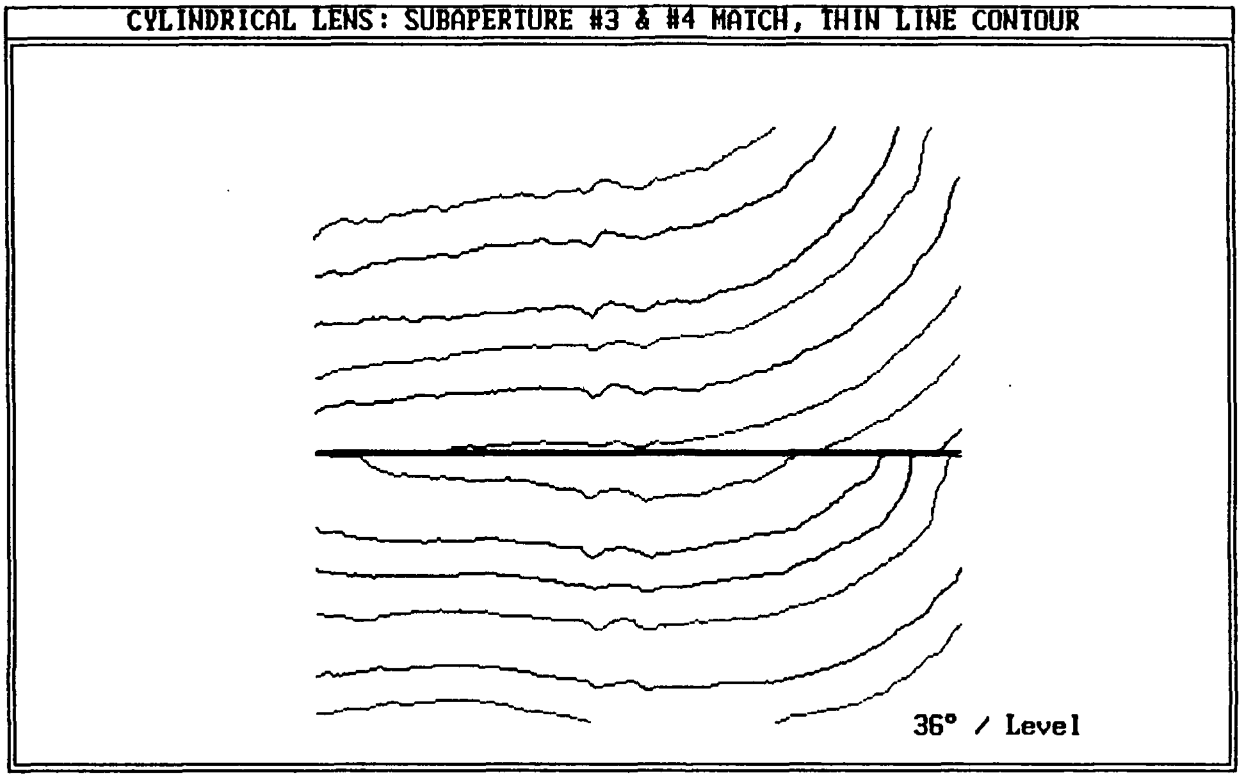


FIGURE 9C: PHASE MEASUREMENT SHOWING LEAST SQUARE FITTING IN OVERLAP REGION FOR SUBAPERTURE INTERFEROGRAMS # 3 AND 4

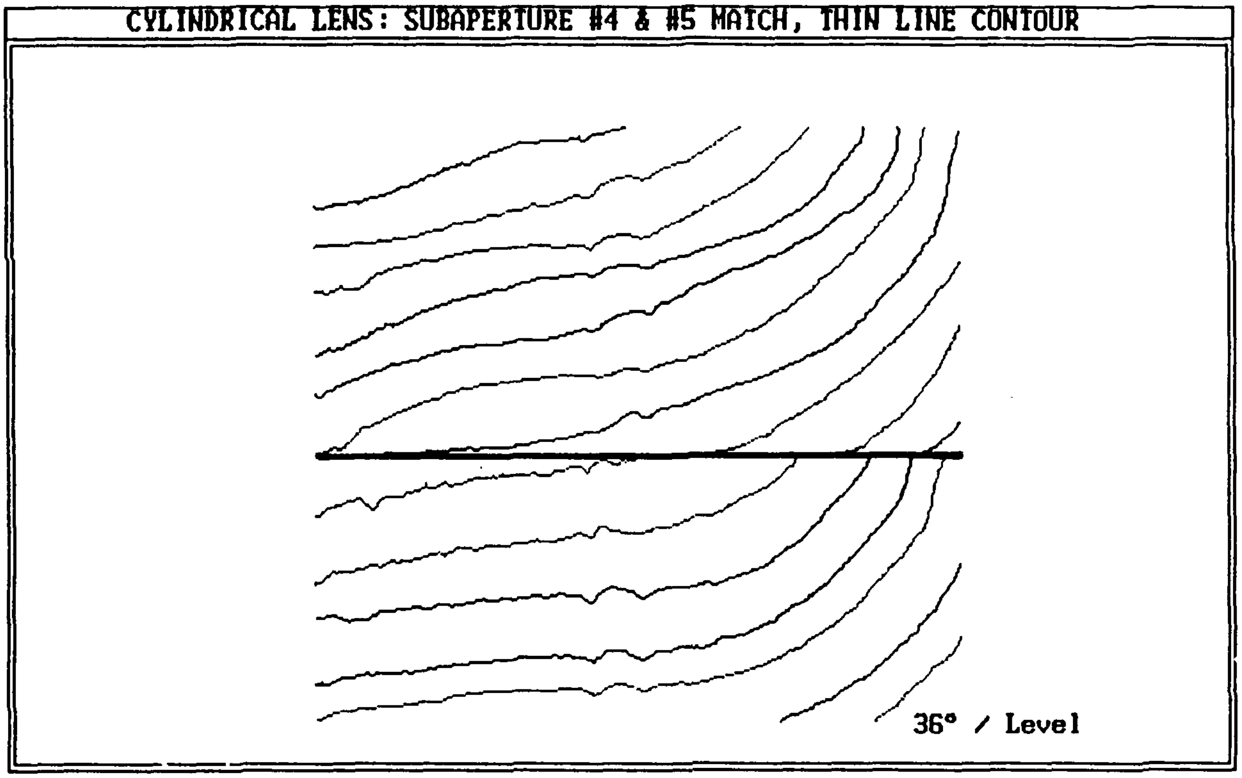


FIGURE 9D: PHASE MEASUREMENT SHOWING LEAST SQUARE FITTING IN OVERLAP REGION FOR SUBAPERTURE INTERFEROGRAMS # 4 AND 5

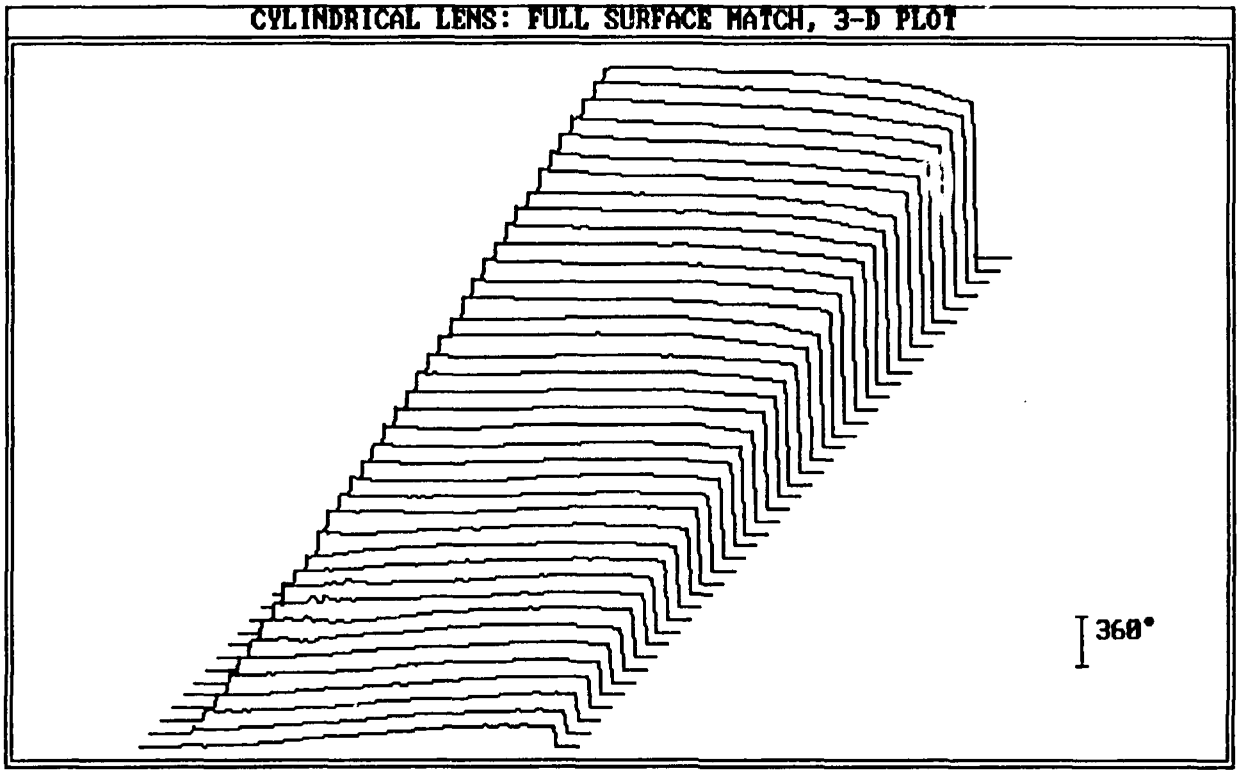


FIGURE 10A: SYNTHESIS OF FULL-SURFACE PHASE MEASUREMENT FROM 5 SUBAPERTURE INTERFEROGRAMS (3-D ISOMETRIC PLOT)

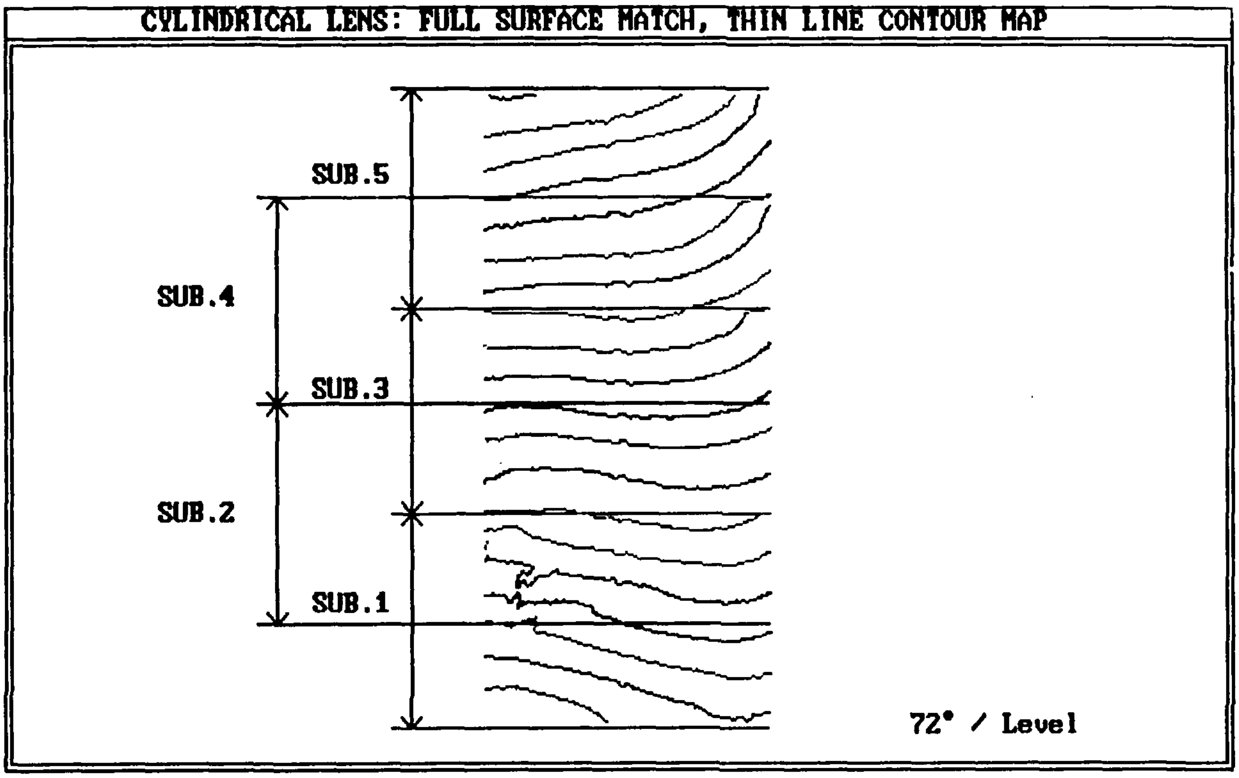


FIGURE 10B: SYNTHESIS OF FULL-SURFACE PHASE MEASUREMENT FROM 5 SUBAPERTURE INTERFEROGRAMS (CONTOUR MAP)

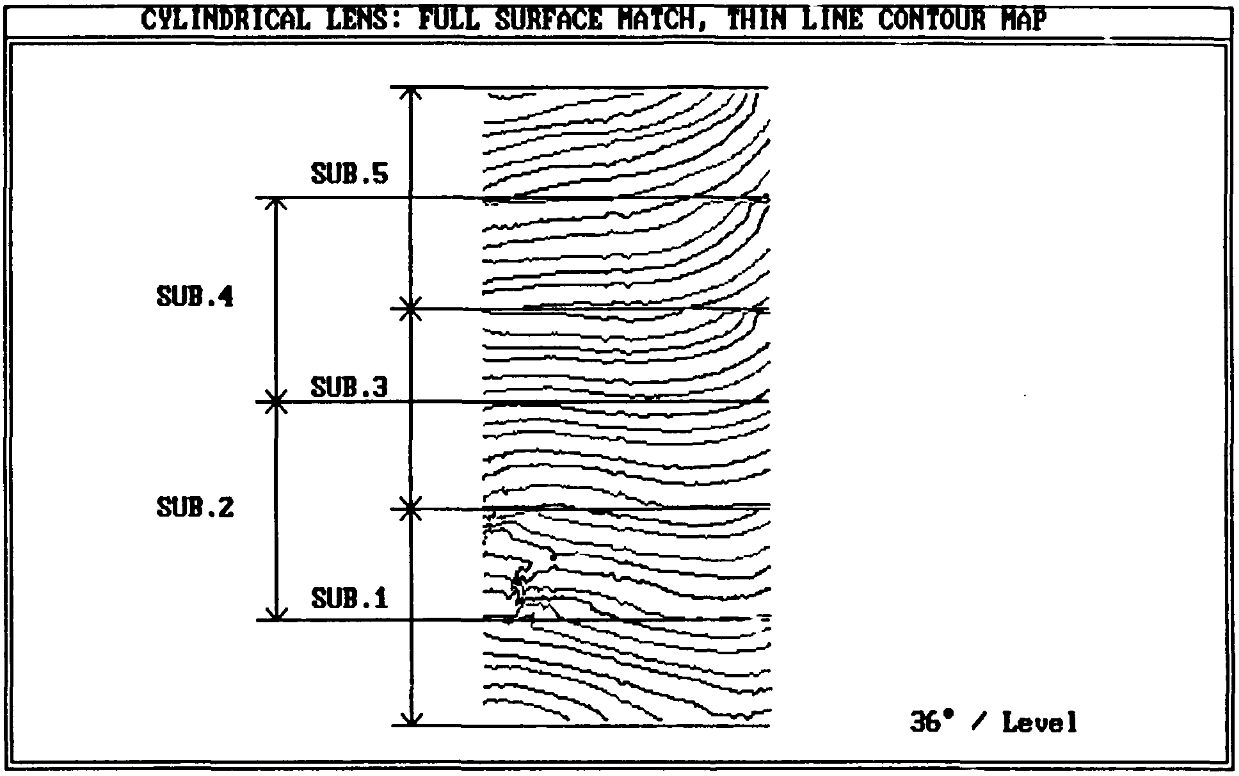


FIGURE 10B': SYNTHESIS OF FULL-SURFACE PHASE MEASUREMENT FROM 5 SUBAPERTURE INTERFEROGRAMS (CONTOUR MAP)

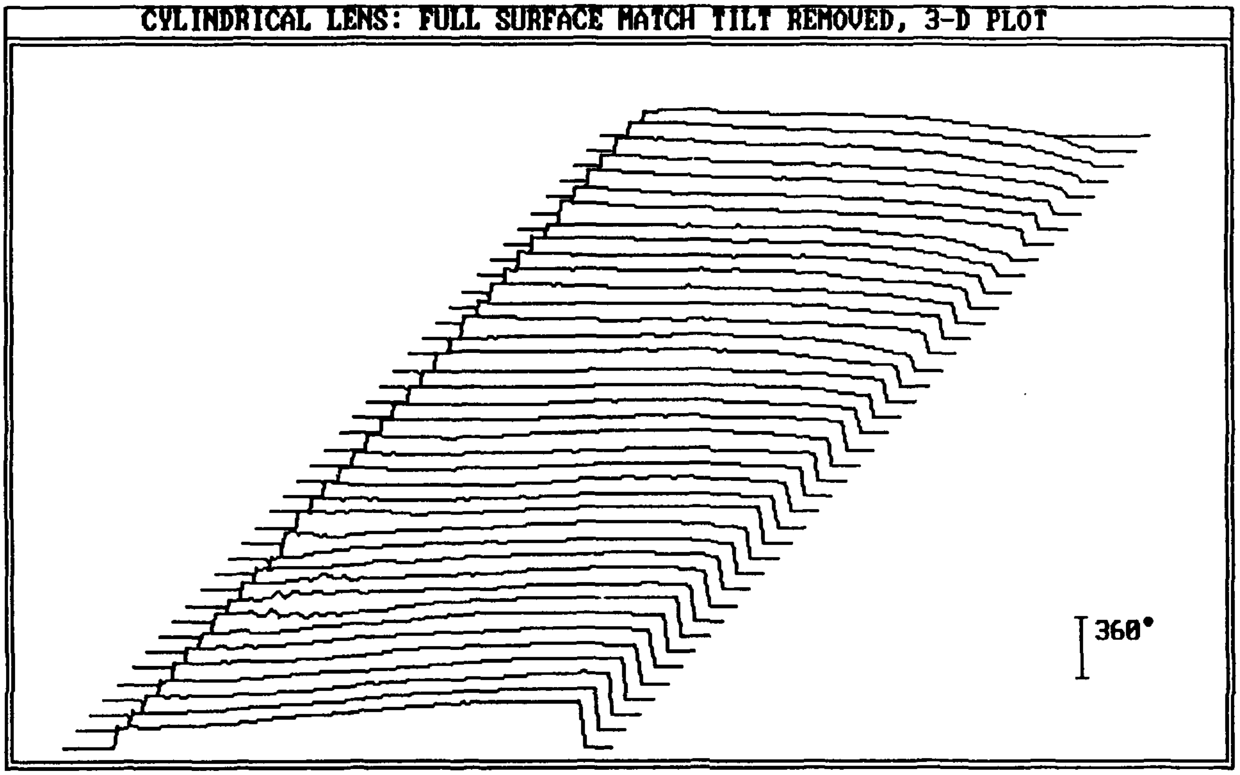


FIGURE 11A: SYNTHESIS OF FULL-SURFACE PHASE MEASUREMENT FROM 5 SUBAPERTURE INTERFEROGRAMS WITH TILT REMOVED (3-D ISOMETRIC PLOT)

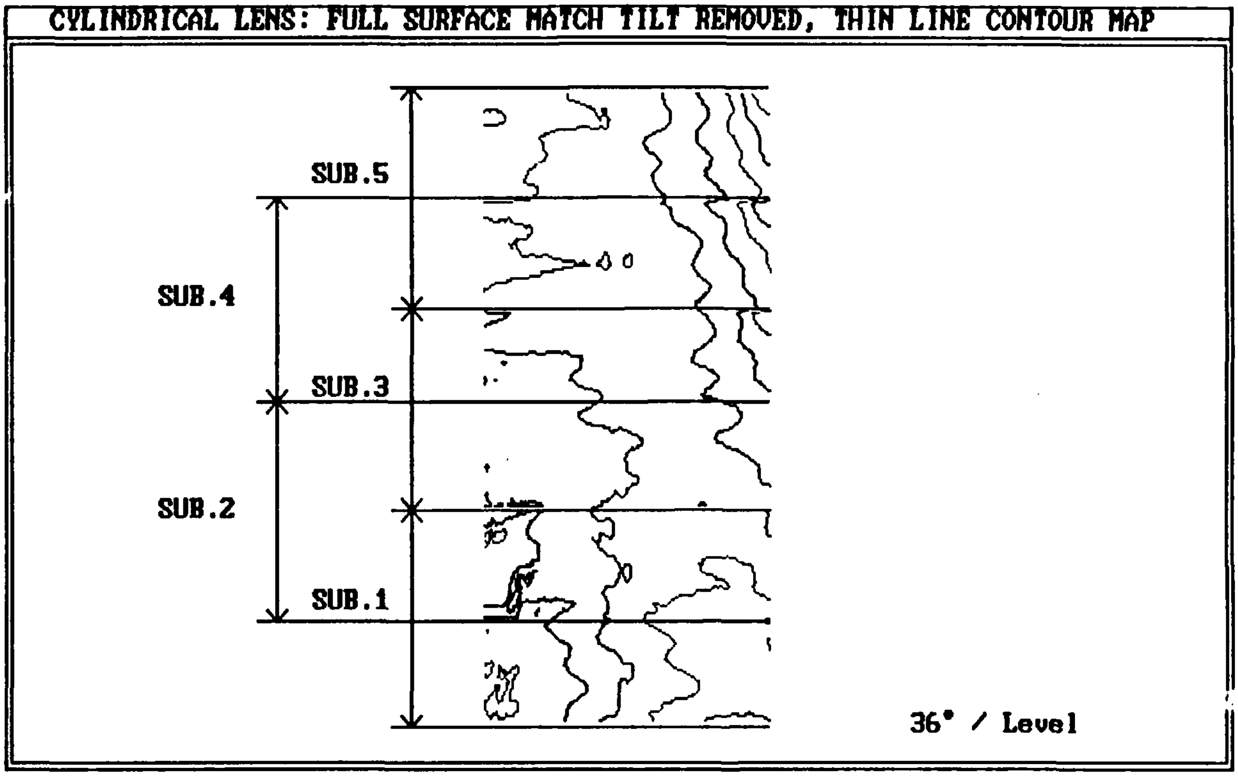


FIGURE 11B: SYNTHESIS OF FULL-SURFACE PHASE MEASUREMENT FROM 5 SUBAPERTURE INTERFEROGRAMS WITH TILT REMOVED (CONTOUR MAP)

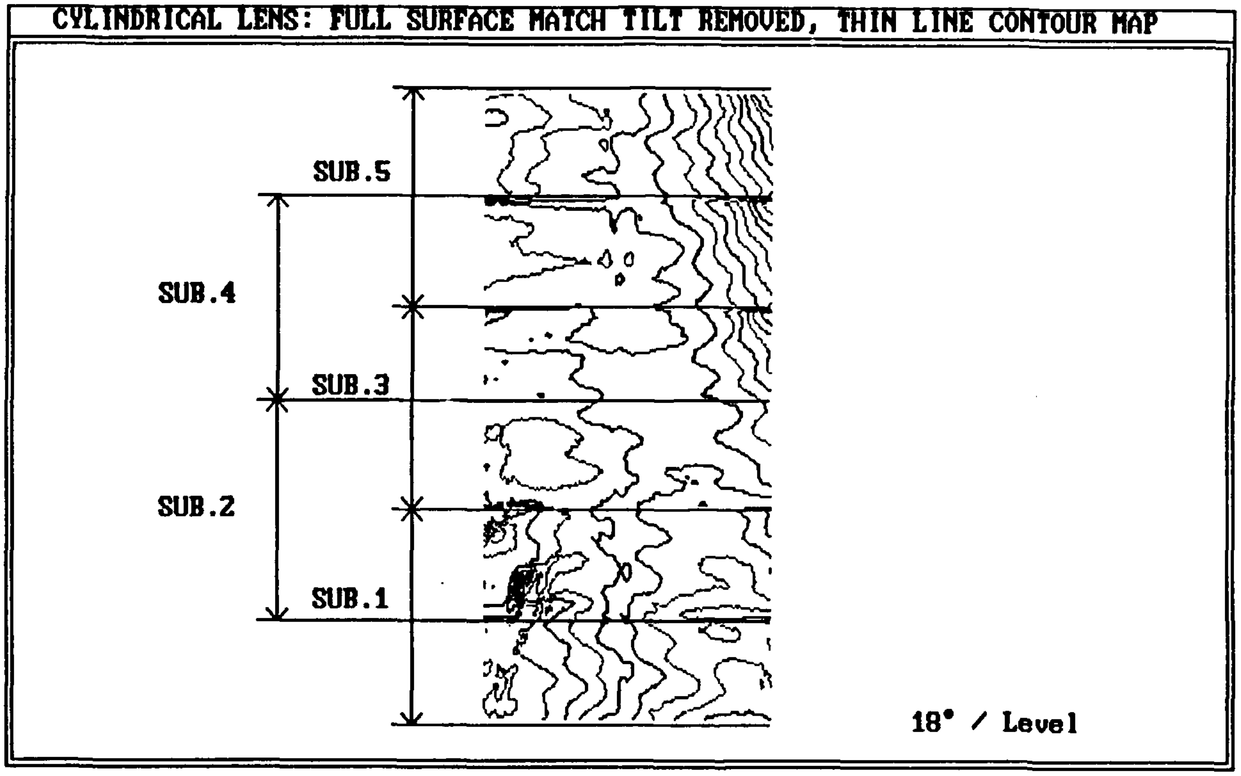


FIGURE 11B': SYNTHESIS OF FULL-SURFACE PHASE MEASUREMENT FROM 5 SUBAPERTURE INTERFEROGRAMS WITH TILT REMOVED (CONTOUR MAP)